D.G. McFETRIDGE

Government Support of Scientific Research and Development: an economic analysis

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GOVERNMENT SUPPORT OF SCIENTIFIC RESEARCH AND DEVELOPMENT: AN ECONOMIC ANALYSIS

1

The rationale for state intervention in the allocation of resources to scientific research and development

1.1 INTRODUCTION

The record of the public discussion of national science policy contains many reasons why the government of Canada should intervene to increase the value of resources allocated to domestic scientific R&D. Some of these reasons centre around national prestige. Many have argued that more R&D is necessary to prevent Canada from 'falling behind in the technological race' and becoming 'a second rate country.' Others have argued that Canada simply must have 'a presence' or 'a capability' in a number of new technologies. Still others have argued that more domestic R&D is necessary to 'promote growth' and 'create jobs.'

This study takes the view that any increase in the value of resources allocated to R&D must be assessed in the light of its effect on the value of goods and services which can be produced with the nation's resource endowment. The first task of any proponent of state action to increase the value of resources allocated to R&D must be to demonstrate, within the type of framework to be discussed in this study, that such action will increase national income. Society may, on occasion, choose to allocate additional resources to R&D even when it is demonstrated that this will draw resources away from activities in which they are more productive and thus reduce national income. The support of scientific research in universities, based on a social commitment to the accumulation of knowledge for its own sake, may be a case in point. A decision such as this is a political one and, provided the members of society are aware of their alternatives, it evokes no comment here. This study does comment upon the incorrect reasoning which has led many writers and policy makers to assert that a greater R&D effort will

increase our national income in cases where it clearly will not do so. It might also be added that it is the suspicion, or perhaps the bias of the author, that, given a choice between the achievement of a goal such as the enhancement of national prestige and a higher real income, Canadians would choose the latter. That is, it is better to be 'a second rate country' if that status entails a higher real income for the country's inhabitants.

A second possible bias inherent in this study is its assumption that, unless proven otherwise, the normal operation of markets will effect an efficient deployment of resources. State intervention can be justified only if it can be demonstrated that there is a reallocation of resources which would increase national income and that the market, if left to itself, would not effect this reallocation.

When evaluating a policy proposal, then, this study asks two fundamental questions. First, would the implementation of the policy result in an increase in the real income of Canadians as a group? Second, if there are measures which would increase the real income of Canadians, why is it not in the interest of some individual or group of individuals to undertake them? Why must it be the state that undertakes them?

It might be argued that in the case of innovative activity these questions are inherently unanswerable. Research and invention are not, some might say, amenable to economic analysis.

> There are a great number of influences that may induce invention. These may include personal gain, curiosity, the outpourings of genius, the pressure of necessity, the type of competition, random and chance events and economic forces in general ... It is tempting to treat invention as a process outside the economic system. Creativity is such a tender plant and so susceptible to the enemies of promise that it is difficult to believe that it can be forthcoming in a predictable and ordered fashion. There is something special about the act of invention. It would seem incongruous that it should be nurtured by mundane economic forces.[1]

If it is the case that technical progress is fundamentally a matter of genius or of chance and is not related in any systematic manner to economic forces, the analysis which appears in the following chapters has very little relevance. Indeed, if the innovative activity is primarily serendipitous, government science policy with its associated patent grants, subsidies, tax concessions and exhortations to

1 Parker (1974, 31). A summary of the extensive debate which occurred during the nineteenth and early twentieth centuries regarding the role of economic motivation in determining the pace of inventive activity is provided by Plant (1934).

do more research is also irrelevant. The actions of the state will have no effect on the pace of technical progress.

Fortunately for science policy and for this study, the predictions of economic model of invention have been in accord with events. In his assessment of Jacob Schmookler's (1966) path-breaking work Parker concludes

> Apparently invention is susceptible to and regulated by economic forces. The prospect of higher profits will induce effort. There is at any time a stock of unfinished inventions which are brought to fruition by the inducement of higher profits in expanding industries, or as a response for additional output when capacity is at a premium. Invention is not outside the economic system. Creativity and ingenuity respond to the stimulus of attractive prospects ... 'In short, the output of technological advances is sensitive to the same economic factors that influence the output of more pedestrian products and services.'(33)

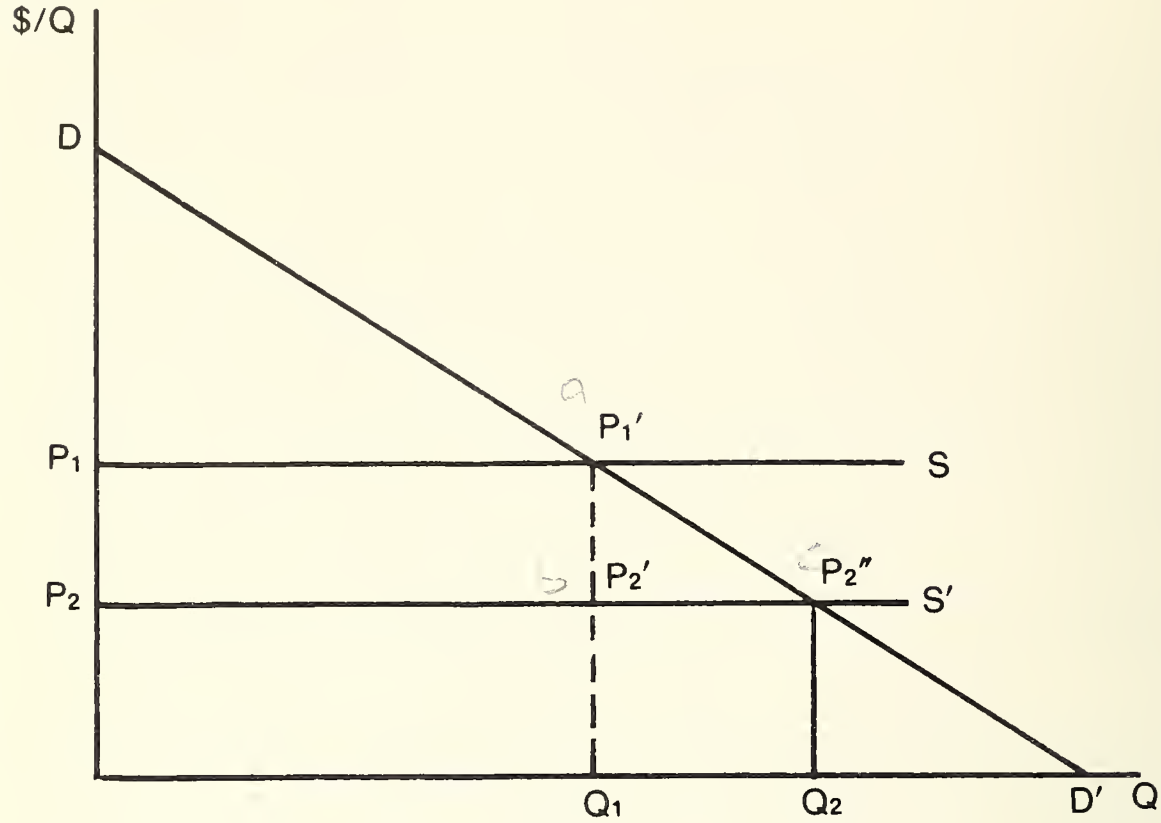
Thus reassured, one is able to proceed with the construction of an economic model of invention. One such model is set out in Section 1.2. It incorporates an idealized set of assumptions which include perfect certainty. It is used to enumerate the circumstances under which the market may fail to allocate sufficient resources to scientific research and development, thus giving rise to the possibility of the type of state intervention which would increase national income. In Section 1.3 risk is introduced. Finally, in Section 1.4 the reasons for state intervention advanced by other participants in the discussion of science policy are examined, again, within the framework described above.

1.2 STATE INTERVENTION UNDER PERFECT CERTAINTY

In this section a model owing much to the work of Griliches (1958), Nordhaus (1967), and Scherer (1972) is employed for the purpose of determining the allocation of resources to the production of new knowledge which will occur under alternative institutional frameworks. It is then possible to assess the merits of alternative types of state intervention. The model analyses the consequences of the production of a particular type of new knowledge, that embodied in a cost reducing process innovation. The conclusions reached can be generalized. The model can also be adapted to deal with other types of new knowledge and this possibility will be discussed briefly.

Consider the competitive industry producing good X under the cost and demand conditions illustrated in Figure 1. A process innovation which, if adopted, would have the effect of shifting the long-run supply function downward to S' becomes available. If all producers are able to adopt the invention without paying the inventor, the market price of good X will be bid down to P_2

Figure 1



and equilibrium output will increase to Q_2. The social gain per period from this innovation is given by the area $P_1P_1'P_2''P_2$. Part of this $(P_1P_1'P_2)$ is the reduction in the value of the resources required to produce the initial output. The balance of gain, $P_1'P_2''P_2'$, is the consumers' surplus on the additional output of the industry.

If we let $\dot{C}$ be the percentage reduction in the supply price $[(P_1 - P_2)/P_1]$ which results from the innovation, and ϵ be the elasticity of demand for product X at P_1, then, for small values of $\dot{C}$, the present value of the flow of social benefits resulting from this process innovation can be written as

$$W = [P_1Q_1\dot{C} + \tfrac{1}{2}\epsilon P_1Q_1\dot{C}^2]/r \tag{1}$$

The flow of benefits is assumed to be perpetual and is discounted at rate r, the social discount rate. The present value of this flow is an increasing function of the value of the pre-innovation sales of good X, the elasticity of demand for good X, and the percentage reduction in costs (supply price) achieved.

The present value of the change in the social benefit which results from a change in the percentage cost reduction achieved is

$$W' = P_1Q_1(1 + \epsilon\dot{C})/r \tag{2}$$

Expression (2) is the marginal social benefit from an increase in the rate of cost reduction achieved. It is also an increasing function of the rate of cost reduction achieved.

We now assume, as seems reasonable, that the rate of cost reduction achieved is an increasing function of the value of resources allocated to research and development in this particular area or

$$\dot{C} = f(R) \qquad f' > 0. \tag{3}$$

This implies an inverse relationship

$$R = g(\dot{C}) \qquad g' > 0, \tag{4}$$

which states that the value of resources allocated to R&D is an increasing function of the rate of cost reduction desired. In addition we assume that the R&D cost of successive increases in the rate of cost reduction is itself increasing. Thus the g' function has a slope which is positive and increasing.

The maximization of social benefit net of R&D cost from cost reduction requires the maximization of

$$W - g(\dot{C}),$$

which implies that the value of resources allocated to the development of process innovations in the production of good X be such that

$$W' = g'(\dot{C}).$$

The determination of the optimal rate of cost reduction is illustrated in Figure 2. Maximization of the present value of the flow of social benefits net of R&D cost implies a rate of cost reduction equal to $\dot{C}_1$. This requires the allocation of resources with a present value of

$$\int_0^{\dot{C}_1} [g'(\dot{C})]d\dot{C} = R_1$$

to R&D and implies a social benefit, net of R&D cost of

$$\int_0^{\dot{C}_1} [W' - g'(\dot{C})]d\dot{C}$$

which is represented by area V in Figure 2.

The optimal rate of cost reduction is $\dot{C}_1$. We must now consider the rate of cost reduction that will be achieved under alternative institutional environments. Assume, first, that the owners of the resources allocated to the development of

this process innovation have no enforceable property right. Any producer of good X can adopt the innovation without payment of royalties. The return to the owners of the resources allocated to the development of the innovation is zero. Since the absence of an enforceable property right is a characteristic of the environment which will be known in advance, the private market will not allocate any resources to R&D. The loss of society, resulting from the inappropriability by those doing the R&D, of the returns to it is given by area V in Figure 2.

The usual response to this type of 'market failure' is to recommend that the state use its borrowing or taxing power to allocate resources with a value of R_1 to R&D and thus achieve the optimal rate of cost reduction. R&D is then conducted by state agencies or by private agencies under contract to the state.

An alternative response is for the state to award the owners of the resources devoted to the development of the process innovation an enforceable property right. One such property right would be a patent of unlimited duration. The patentee then owns the right to an innovation which allows production of good X at a per unit cost $(P_1 - P_2)$ below the prevailing market price. The maximum per unit royalty which the patentee can extract from X producers is slightly less than $(P_1 - P_2)$ per period. In this case the market price can be assumed to remain at P_1. The royalty income of the patentee approaches $P_1P_1'P_2'P_2$ per period. The present value of this income is

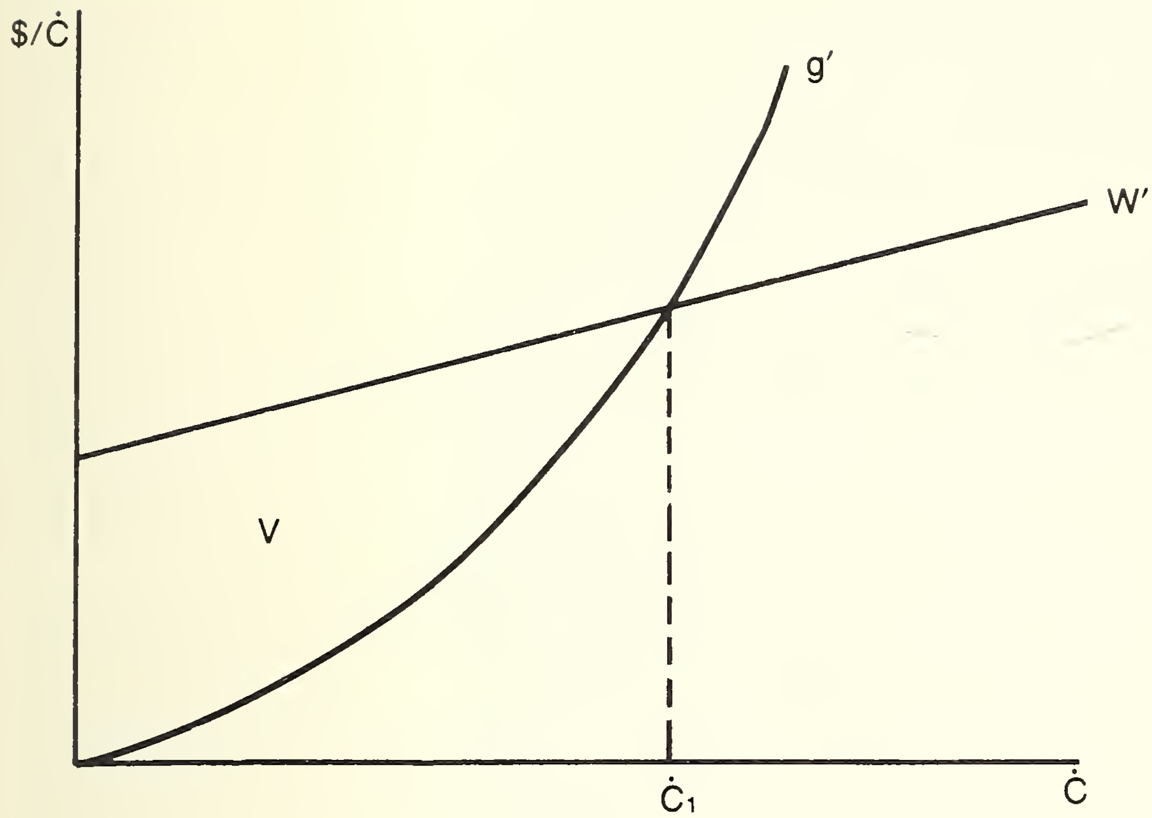
$$I = (P_1Q_1\dot{C})/r \tag{5}$$

This is also the value of the social benefit resulting from the innovation. All else being equal, I will fall below the maximum possible social benefit, W, by the amount of the present value of the consumers' surplus on the foregone consumption of X The I' function $(\partial I/\partial \dot{C})$ will also lie below the W' function in Figure 2. The optimal rate of cost reduction will be lower than $\dot{C}_1$ and the social benefit net of R&D cost will be less than V.

Had the process innovation been made freely available to all X producers, the price of X would have been bid down to P_2 and the social benefit implied by the W function achieved. This illustrates the dilemma of the patent system. The owners of the rights to an innovation can, in this case, earn a positive return on the innovation only by restricting its use. The patent system provides the incentive to allocate resources to R&D but does so at the cost of restricting the use of the results of such R&D.

If the patentee is able to effect a perfectly discriminatory pricing system for X, this problem disappears. The patentee could then monopolize X production and operate along demand schedule $P_1P_1'D_1$ (Figure 1) so as to extract

Figure 2



$P_1P_1P_2''P_2$ per period from the consumers of X. The resulting social benefit, all of which accrues to the patentee is, again, given by the W function. The social benefit net of R&D costs is given by area V in Figure 2. A patent grant of unlimited duration, coupled with the ability to discriminate perfectly in the pricing of X, thus yields the same social benefit as the state conduct of R&D with its results being made available free to all X producers. While these alternatives are, under the present set of assumptions, equivalent in efficiency terms, they differ substantially in their distributional consequences. The benefits of state conducted R&D accrue to the consumers of good X. Under the patent system envisaged here the benefits accrue entirely to the patentee. The reader should note for future reference that under the first regime, to the extent that good X is exported, the benefits of the R&D accrue to foreign consumers and the social return to the resources allocated to R&D is reduced. Under the second regime, the resources allocated to R&D are foreign owned, the gain W accrues to foreigners, and the benefits to Canada are nil. Canadians are equally well off before and after the innovation.

Abstracting, for the present, from the problem of the nationality of both the ownership of the resources allocated to R&D and the consumers of good X, society's choice between these idealized alternative regimes should be based upon the relative costs of operating them. Both the government and the patentee must use resources to monitor the efforts of those involved in the R&D operation. In this respect the costs of the alternative systems are roughly equivalent.

The patentee must also use resources to ensure that those using the innovation pay for its use. In particular, the patentee will incur the cost of operating a discriminatory pricing system for good X.[2] Because it makes the innovation available without charge, the government does not incur this cost. It is in the interest of the patentee to achieve an allocation resources to R&D such that net private benefit ($W - g(\dot{C})$ in this case) is maximized. If R&D is conducted by the government, the officials responsible for determining the value of resources allocated to R&D will also be guided by self-interest. Since any net benefits do not accrue to them, it is not in their interest to choose an allocation that maximizes net benefits. It is an implication of the theory of bureaus that it is in the interest of government officials to choose an allocation which exhausts net benefits.[3] That is, unless other behaviour is forced on them, government officials will allocate resources with a value greater than that which maximizes social net benefit to R&D. The government, therefore, incurs the costs associated with enforcing maximizing behaviour on its officials. If this exceeds the cost incurred by a patentee in the appropriation of the net benefits of the innovation, the idealized patent system will achieve an efficient allocation of resources to R&D at a lower cost than will the government conduct of it. If the patentee is a corporation rather than an individual, its owners will also incur the cost of enforcing maximizing behaviour on its officials.[4] Government conduct of R&D would then be the lower cost alternative.

To summarize, under conditions of perfect certainty one finds that government conduct of R&D with the results made freely available and a patent grant of unlimited duration coupled with the right to engage in price discrimination are equivalent in terms of their allocative efficiency. Distributional considerations notwithstanding, the choice between these two regimes must be based on the enforcement costs each entails. These are the costs of enforcing both property rights and maximizing behaviour. There is no a priori reason to believe that one regime necessarily entails higher enforcement costs. The choice between regimes will, therefore, be made on empirical rather than theoretical grounds.

In the idealized environment assumed above there is no need for the partial subsidization of R&D. If there is no property right, the subsidy must cover all R&D costs. It is then an R&D contract. If a property right such as that defined above exists, no subsidy is required. If, however, we assume that the returns to

2 For a simple analysis of the allocative efficiency effects of perfect price discrimination when such discrimination is not costless, see Williamson (1975, 11-13).

3 For a summary of the literature on the level of activity chosen by a government agency, see Hettich (1975).

4 For a theoretical discussion of the costs of enforcing maximizing behaviour on corporate officials, see Jensen and Meckling (1975).

the innovation are partially appropriable by the owners of the resources allocated to innovative effort, a rationale for partial subsidization emerges.

Assume now that the owners of the resources devoted to the innovation are granted a limited property right. Society gives them the right to collect royalties from X producers for T periods. At the end of T periods the innovation may be used without payment of royalties. Discriminatory pricing of good X is forbidden.[5] Producers of X will then pay a maximum of $(P_1 - P_2)$ per unit of X for the rights to use the innovation. The price of X remains at P_1 for the duration of the patent term, after which it is bid down to P_2. While the patent is in effect, then, neither the price nor the output of good X is changed.

The royalty income of the patentee is $P_1 Q_1 \dot{C}$ per period. The present value of the flow of royalty income is

$$G = (P_1 Q_1 / r)\ (1 - e^{-rT})\dot{C}. \tag{6}$$

Expression (6) is also the privately appropriable portion of the flow of benefits resulting from the innovation.

The present value of the flow of social benefits resulting from the innovation is

$$B = (P_1 Q_1 / r)\dot{C} + (\epsilon P_1 Q_1 e^{-rT} / 2r)\dot{C}^2. \tag{7}$$

It will be recalled that expression (1) yielded the value of the maximum possible social benefit, W, which could result from a given process innovation. This occurred under circumstances of perfect appropriability or government conduct of R&D. Given the situation of imperfect appropriability now being investigated, the social benefit, B, is given by expression (7). Other things being equal, as the patent term tends to zero, social benefit B approaches the maximum possible social benefit, W. A glance at expression (6) reveals that as the patent term approaches zero, privately appropriable benefits do likewise. This again illustrates the dilemma of the patent system. An increase in appropriability increases innovative effort but reduces the social benefit derived from that effort.

As the patent term, T, tends to infinity, the privately appropriable benefits, G, and the social benefit, B, tend to equality at a value which lies below the

5 For a description of the current Canadian patent system, see Economic Council of Canada, *Report on Intellectual and Industrial Property* (1968), 45-101). The present patent term, T, is seventeen years. Whether price discrimination by a patentee is actually forbidden by current legislation is unclear. See the *Report on Intellectual and Industrial Property* 70-75 for a discussion of this point. The case in which innovations are not patentable but can be kept secret and are therefore not copied for T periods is identical.

maximum possible social benefit, W, by the present value of the consumers' surplus lost by preventing good X from being sold at P_2.

Society is then left with a choice between a short patent term which implies that relatively little inventive effort will be forthcoming and a long patent term which entails a loss of consumers' surplus due to the failure of the price of good X to follow its production cost downward. Nordhaus (1967) has responded to this dilemma by finding the patent term which maximizes social benefits, B. In this study, we take the patent term as given and find the subsidy system which maximizes social benefits.

From expressions (1), (6), and (7), we find the change in the maximum possible social benefit resulting from a change in the rate of cost reduction

$$W' = P_1Q_1/r + (P_1Q_1\epsilon/r)\dot{C}, \tag{8}$$

the change in the actual social benefit resulting from a change in the rate of cost reduction

$$B' = P_1Q_1/r + (\epsilon P_1Q_1e^{-rT}/r)\dot{C}, \tag{9}$$

and the change in the present value of the patentee's income resulting from a change in the rate of cost reduction

$$G' = (P_1Q_1/r)\ (1 - e^{-rT}). \tag{10}$$

Equations (8) – (10), together with the derivative of equation (4), are plotted in Figure 3.

A rate of cost reduction equal to $\dot{C}_G$ will maximize the present value of the net income of the patentee. At this point the marginal R&D cost of a change in the rate of cost reduction is just equal to the present value of the marginal change in income which results from it. Achievement of this rate of cost reduction requires R&D expenditures with a present value of

$$\int_0^{\dot{C}_G} g'(\dot{C})d\dot{C}.$$

The present value of the patentee's income is an increasing function of the initial value of industry output. The model thus predicts that the profit maximizing rate of cost reduction and level of R&D expenditures is an increasing function of the initial value of industry output. Schmookler and Griliches (1963) found the evidence on patenting activity to be consistent with this prediction. Among their findings are that patenting activity varies with value added

across industries at any point in time and that patenting activity within an industry varies with past levels of industry value added.

For a given rate of cost reduction and marginal social benefits exceed the marginal income of the patentee. This is due, first, to the limited term of the patent. Social benefits are assumed to continue indefinitely but are appropriable only during the term of the patent. Second, on the expiry of the patent, the price of X is bid down to P_2, resulting in an increase in consumers' surplus. The present value of this increase is

$$(\epsilon P_1 Q_1 e^{-rT}/r)\,\dot{C}.$$

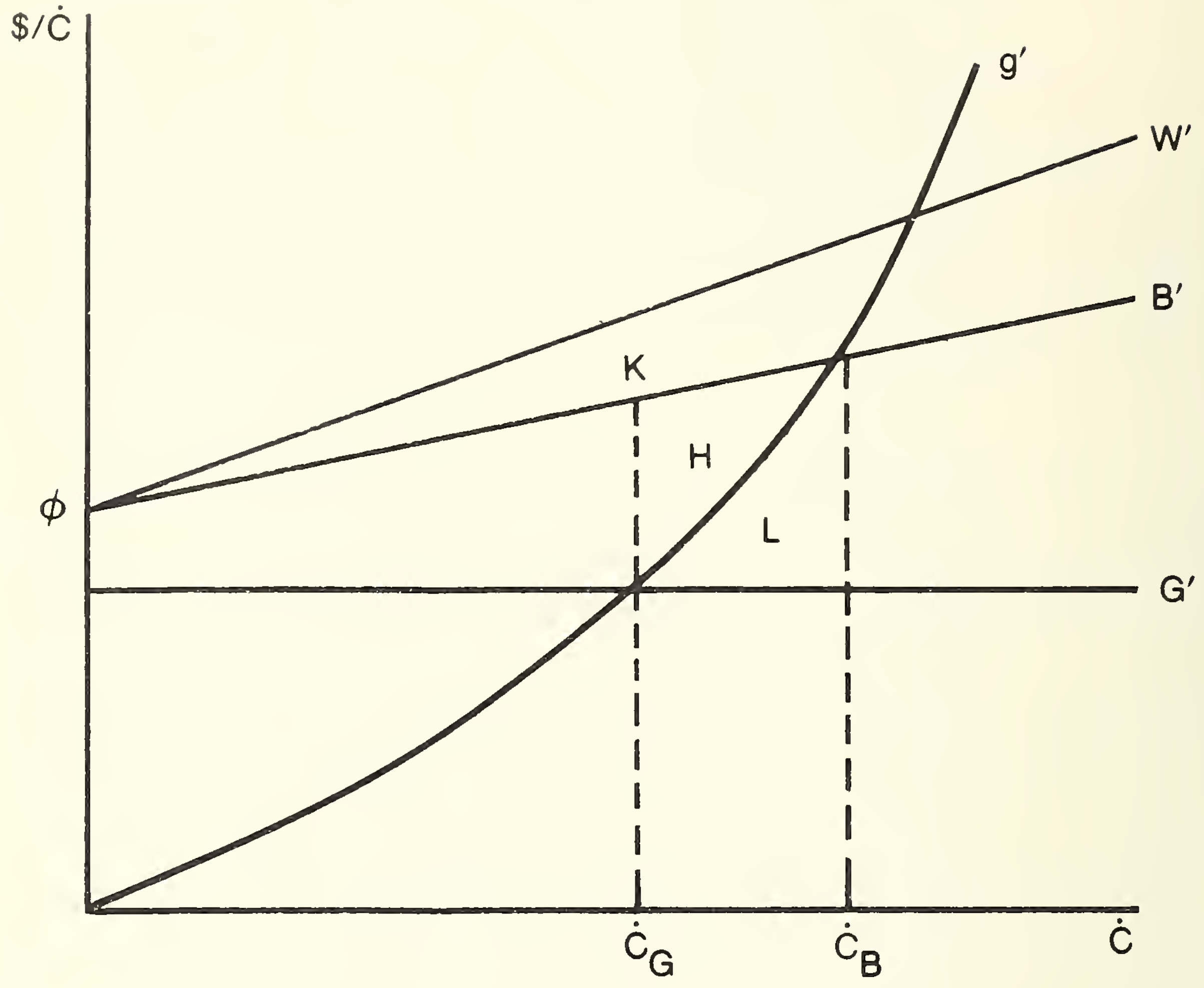
Because the marginal social benefit exceeds the marginal private benefit of any given rate of cost reduction, the rate of cost reduction which is optimal from a social point of view, $\dot{C}_B$, exceeds that which maximizes the wealth of the owners of resources allocated to R&D. The divergence between the rate of cost reduction which results from the operation of the market and that which is socially desirable can be removed by paying a subsidy with a present value given by area L in Figure 3 to owners of resources which are to be allocated to R&D. The present value of the social gain resulting from the payment of this subsidy is given by area H.

Although the subsidy increases the net benefits which flow from cost-reducing process innovations, the combination of subsidies with patent grants of finite duration does not result in the maximum possible net benefits. The difference between the latter and those achieved under this system is given by area K. K is equal to the present value of consumers' surplus lost while the patent is in effect. Owing to the collection of a per unit royalty of $P_1 - P_2$, the price of X remains at P_1 which exceeds the new long-run supply price of X, P_2, and consumers' surplus with a present value of $(\epsilon P_1 Q_1\ (1 - e^{-rT})/2r)\dot{C}^2$ is lost.

As the patent term decreases, both the potential social gains from subsidization and the optimal subsidy as a proportion of R&D expenditures increase. To take the extreme cases, as the patent term approaches zero, B' tends to equality with W'. G' tends to zero, however, and the market allocates no resources to R&D. The optimal subsidy covers all R&D costs. As the patent term approaches infinity, the B' and G' functions become horizontal with intercept ϕ (see Figure 3). There are no gains to be made from the subsidization of R&D. The optimal subsidy is zero.

To summarize, given the imperfect appropriability associated with a limited term patent grant or with an innovation which can be kept secret for a limited time, the subsidization of R&D is warranted on allocative efficiency grounds. Unless the patentee can discriminate perfectly in setting the price of good X, the social benefits produced by this patent-subsidy combination can never be as great as those produced by state conduct of R&D (100% subsidy, no property

Figure 3



rights) or by a patent grant of unlimited duration coupled with the right to discriminate perfectly in the pricing of *X*.

A similar rationale for the subsidization of R&D can be derived for the case of a product innovation. It can be shown that only in the case of an unlimited patent term and perfect discrimination in the pricing of the new product will the market allocation of resources to R&D also be socially optimal. Given the partial appropriability of the returns to R&D discussed above, subsidization of R&D is again justified on allocative efficiency grounds.

Although they have had little impact on the formation of science policy, the conclusions arising from the above analysis have assumed the status of conventional wisdom among economists. They are not, however, without their critics. Among the more important criticisms are those raised by Hirshleifer (1971) and Eads (1974).

Hirshleifer has argued that, in addition to appropriating all or part of the social value (benefit) of his invention, an inventor may use his 'inside' knowledge of the ultimate redistributive effects of the invention for speculative purposes. A process innovation which lowers the cost of producing good *X* may, for example, reduce the value of firms producing competing good *Z*. Inside knowledge of the invention and its subsequent effects would, in this case, induce

insiders to take up a short position in the shares of Z producers. By exploiting the ignorance of other investors regarding the future value of Z producers, the inventor or other insiders could earn returns in excess of the social benefit resulting from the invention itself. Once this knowledge has had its effect on relative prices, there are, of course, no further gains of this nature to be made. The size of his speculative income therefore depends on the extent to which an inventor can monopolize and act upon his foreknowledge of the effects of the invention.

Hirshleifer argues that because an inventor could conceivably earn an income in excess of the social value of his invention and because the size of the speculative gains resulting from an invention need not be related to its social value, the possibility of an over-allocation of resources to inventive activity in general or to inventive activity which generates large speculative gains exists. In response it can be argued that this effect, while it undeniably exists, is likely to be quantitatively unimportant. First, inventive activity is not the only activity which has the potential to generate knowledge of the future course of relative prices. The speculative gains it does generate need not make it especially attractive relative to other activities. Second, the technical environment and hence the probability of inventions of a given type and magnitude will be widely known and thus reflected in market prices. Very little information will be truly 'inside' information. Third, the relatively high transactions costs involved, for example, in entering into a wide range of futures contracts, will preclude the exploitation of any truly 'inside' information on a scale sufficient to result in a significant augmentation of an inventor's income.

Eads argues that the deviation between the social and private benefits of new inventions is not the only relevant distortion. The derived demand for R&D may, as a result of other types of government intervention or of cartel behaviour, exceed that which would otherwise prevail. The subsidy then aggravates rather than ameliorates the misallocation of resources. As an example Eads cites the effect of non-price competition by airlines on the rate of introduction of new aircraft. He argues that, had fares been allowed to reflect the differing qualities of aircraft available, the rate of introduction of new aircraft would have been slower (this is confirmed by Canadian observers) and fewer resources would have been devoted to R&D in the aircraft industry. Subsidization of the R&D expenditures of aircraft builders resulted in further increases and, in Eads view, an even greater misallocation of resources.

Eads's criticism is simply one more manifestation of the problem of 'second best.' If there are other distortions in the economy (monopoly, tariffs, or taxes), correcting one, the deviation between the private and social returns to invention, does not necessarily increase national income. As in the aircraft example, above,

distortions may offset one another and the removal of only one of them decreases national income.

This 'second best' problem is a source of some difficulty for those wishing to provide a theoretically sound rationale for virtually any microeconomic policy. In the aircraft case above, the obvious 'first best' policy would have been to allow air fares to vary so that airlines could offer older equipment – lower fare options to travellers and at the same time institute any subsidies necessary to equate the social and private returns to aircraft development. In general, one must advocate that policies which reduce other distortions, especially those in areas of related activity, be implemented along with the R&D subsidy system.

1.3 RISK AND STATE INTERVENTION

Individual R&D projects are risky. Each has a range of possible outcomes. Risk averse individuals will pay more for an asset which yields a given rate of return with certainty than for an asset the returns to which are subject to a probability distribution even though the expected return to both assets is the same. They must, in other words, be compensated for bearing risk. This compensation is part of the cost of doing R&D. It has been argued that while individuals must be compensated for bearing risk, the state or society as a whole need not be. Risk bearing is a private but not a social cost. In this case society should undertake the risk bearing function. In operational terms this implies that the government do all R&D or that the government have R&D done by firms or individuals on cost plus contracts. It is conceivable that the state offer to insure all R&D projects for the perfect certainty rate of return.[6] Through the use of partial subsidies and forgivable loans the state can also bear part of this risk associated with a given project.

In our consideration of risk bearing as a rationale for state intervention we deal with three questions. These are:

1 What is the mechanism by which the cost of risk bearing can be reduced or eliminated?
2 What are the limitations on efforts to reduce the cost of risk bearing?
3 Can these limitations be overcome more readily by the state than by the market?

If it can be demonstrated that risk can be borne at lower cost through the state than through the market, we shall assign a risk bearing role to the state.

6 All projects with an expected return equal to or greater than the perfect certainty rate of return would be guaranteed the latter. Anything in excess of the latter would accrue to the state.

Risk can be reduced and, under certain circumstances, eliminated entirely by diversification. If the outcomes of all R&D projects are statistically independent, their rates of return can be viewed as independent random variables. The mean rate of return on a portfolio of n R&D projects is

$$\bar{\pi} = \frac{1}{n}\sum_{i=1}^{n} \pi_i,$$

where π_i is the rate of return on the ith project. The expected value of the mean rate of return is

$$E(\bar{\pi}) = \frac{1}{n}\sum_{i=1}^{n} E(\pi_i),$$

which is simply the average of the expected return on each project. If each project has an expected return in excess of the social discount rate, then the expected return on the portfolio will exceed the social discount rate.

The variance of the average return on independent projects is

$$\begin{aligned} \text{var}\ (\bar{\pi}) &= \text{var}\left[\frac{1}{n}\sum_{i=1}^{n} \pi_i\right] \\ &= \frac{1}{n^2}\sum_{i=1}^{n} \text{var}\ (\pi_i). \end{aligned}$$

If the variances of the distributions of each of the π_i are the same

$$\text{var}\ (\bar{\pi}) = \frac{n\ \text{var}\ (\pi_i)}{n^2} = \frac{\text{var}\ (\pi_i)}{n}.$$

The variance of the average return on n independent R&D projects tends to zero as n becomes large. The distribution of possible returns to the portfolio collapses about its expected value. To interpret this intuitively, if projects are independent, very low and very high rates of return will tend to cancel each other out so that, for large portfolios, the average return on the portfolio will be stable. Since there is little or no variation in the return to the portfolio, there is little or no risk attached to holding it. This is the source of the argument advanced by Arrow (1962) that, because there will be little variation in the average return to all R&D projects undertaken by society, society bears little risk and should therefore be indifferent to it.

If the outcomes of the R&D projects are not independent, however, elimination of risk by the simple device of pooling a large number of projects is no

longer possible. Consider the extreme case in which the returns to all projects are perfectly correlated. A tendency in this direction would arise if the returns to all projects were correlated with the business cycle. In this case the variance of the return to a portfolio of n projects is

$$\operatorname{var}(\bar{\pi}) = \operatorname{var}\left(\frac{1}{n}\sum_{i=1}^{n}(\pi_i)\right) = \frac{1}{n^2}\sum_{i=1}^{n}\operatorname{var}(\pi_i)$$

$$+\frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\mathrm{COV}\,(\pi_i\pi_j).$$

If the π_i are perfectly correlated and the variances of the π_i are the same

$$\operatorname{var}(\bar{\pi}) = \frac{\operatorname{var}(\pi_i)}{n} + \frac{1}{n^2}(n)(n-1)\operatorname{var}(\pi_i)$$

$$= \frac{\operatorname{var}(\pi_i)}{n} + \frac{(n-1)}{n}\operatorname{var}(\pi_i) = \operatorname{var}(\pi_i).$$

The variance of the average rate of return to a portfolio of n projects is the same as the variance of the return to each project. The 'naive diversification' of pooling a large number of projects does not reduce risk. From both a social and a private viewpoint risk does exist.

If the returns to individual R&D projects are less than perfectly correlated, some risk can be eliminated by diversification.[7] The simple device of viewing investment projects in the aggregate is no longer sufficient, however, to eliminate risk, and society as a whole can not be indifferent to it.

Risk reduction is an economic good for which risk averse individuals would be willing to pay. One would therefore expect to observe the emergence of institutions which, operating through markets, supplied this good. If, for example, the returns to all R&D projects were independent, an institution which had an equity position in a large number of projects, each of which had an expected return in excess of the (risk-free) social discount rate, would consistently earn a return in excess of the discount rate. That is, the variance of the return to the institution would approach zero. Such an institution would find it

7 To take another extreme case: if the returns to two projects are perfectly negatively correlated, the variance of the average return to a portfolio consisting of these two projects is zero. In this case, risk can be eliminated without resorting to the pooling of a large number of projects. If the correlation is less than perfectly negative, diversification can reduce risk but not eliminate it.

profitable to take an equity position in any R&D project with an expected return in excess of the risk-free discount rate, regardless of the variance of the distribution of its possible rates of return. Two factors militate against the emergence of this type of institution. The first is the 'moral factor.' The absorption by the risk pooling institution of all risk associated with a project relieves those involved of both the costs of its failure and any rewards associated with its success. The independence of their reward from the outcome of the project may alter their efforts and hence the outcome of the project. The shifting of risks changes the incentive system and may reduce the expected return to the project. Where the effect of moral hazard is to reduce the expected return below the risk free discount rate a project will not be undertaken. The dilemma here is that, unless risks are shifted, the project will not be undertaken. If they are shifted, the project will not be worth undertaking.

The second factor militating against risk reduction by the market is the transactions cost associated with determining the expected return to a project, monitoring the activities of those involved in it and enforcing such terms of the contract as the claim of the risk bearing institution to residual returns. The cost of determining potential returns are likely to be particularly high in the case of an R&D project. Inclusion of transactions costs may again result in the reduction of expected return below the discount rate.

In summary, the extent to which risk can be reduced through diversification and the nature of the diversification required is determined by the statistical relationship among the returns to the projects involved. The extent to which the risk reduction achieved via the market mechanism approaches that which is statistically possible depends on moral hazard and transactions cost. These same costs would be incurred by the state if it were to undertake the risk-bearing function. Thus, the extent to which the risk reduction achieved by the state approaches that which is statistically possible also depends on moral hazard and transactions cost. Unless the state can avoid these costs, its undertaking of the risk-bearing function should result in an allocation of resources to risky projects which does not differ from that resulting from the operation of the market. There is, at present, no theoretical reason to believe that the state can avoid the moral hazard and transactions costs incurred by those operating through the market. Further investigation of this issue is clearly desirable. Given the present state of knowledge, however, we must conclude that if a project is 'too risky' in the sense that its expected return after allowing for transactions cost and moral hazard is not sufficient to induce any individual (or group) to bear the non-diversified risk associated with it, then it is also 'too risky' for the state. Conduct by the state of R&D projects which would not be undertaken in a market environment cannot be justified on the basis that the appropriate markets for

risk-shifting do not exist. The absence of such markets may indicate that the costs of risk-shifting outweigh its benefits.[8] There is no reason to believe that this will not also be true of state efforts to undertake this function.

The foregoing has considered the argument that the state engage in risk-bearing because of advantage it might have in the reduction of risk by diversification or risk-pooling. Arrow and Lind (1970) have argued that the state engage in risk bearing because of advantages it has in risk-spreading. That is, because the state spreads a given risk among all taxpayers, the proportion of that risk which will be incurred by each taxpayer is so small that it can be borne without cost.

> ... when the risks associated with a public investment are publicly borne, the total cost of risk-bearing is insignificant and, therefore, the government should ignore uncertainty in evaluating public investments. Similarly, the choice of a rate of discount should in this case be independent of considerations of risk. This result is obtained not because the government is able to pool investments but because the government distributes the risk associated with any investment among a large number of people. It is this risk-spreading aspect of government investment that is essential to the result.[9]

This argument is no stronger than the risk-pooling argument considered above. There are three reasons for its limited influence. First, the proof that the aggregate risk premium tends to zero as the number of taxpayers becomes large requires that the returns to the projects involved be independent. That is, if the outcome of a risky venture is positively correlated with a taxpayer's other income, it can not be shown that the latter will be willing to bear even a very small risk at no cost. Thus, if the returns to all projects are not independent, it is technically impossible to eliminate risk either by risk-pooling or by risk-spreading.

Second, if the aggregate cost of risk-bearing can be reduced by a wider spreading of the ownership of a risky venture, there is obviously scope for a mutually beneficial exchange between owners and non-owners. One might expect that, subject to the limitations of moral hazard and transactions cost, a market would arise to effect such exchanges. Since the type of risk-spreading described by Arrow and Lind forces all taxpayers to undertake a risk-bearing function whether or not they would have chosen to do so, it must be regarded as inferior

8 There may be legal impediments to the emergence of the appropriate risk-shifting institution. If this is the case, the 'first best' solution is to remove the impediment.

9 Arrow and Lind (1970, 366).

to the risk-spreading effected in the market, unless it can be shown that state risk-spreading avoids some of the moral hazard and transactions costs to which market exchanges are subject.

Third, either or both of the costs and benefits of a project may accrue to a subset of taxpayers. The share of the project risk borne by the members of this subset is not necessarily infinitesimal and payment of a risk premium will be required to induce them to bear it. Arrow and Lind concede that

> Benefits accruing to individuals should be discounted according to individual time and risk preferences

and that

> ... finding the marginal rate of return on assets with similar payoffs in the private sector and using this as a rate of discount appears reasonable for discounting those costs and benefits which accrue privately. (377)

The benefits of industrial R&D will be confined to those who perform it and to those using the new products or products produced by the new processes which result from this R&D (see Section 1.2). This may be a relatively small number of individuals and the benefits involved may constitute a relatively large fraction of their wealth. In this case these benefits should be discounted at the relevant private sector discount rate.

In summary, the relevance of risk-spreading is confined to the rather unlikely situation in which rates of return on all projects are independent and both costs and benefits are distributed over a large number of individuals. Even then advocates of state risk-spreading must explain why the risk-spreading which is technically possible can be achieved more efficiently by the state than in the market.

The preceding analysis leads one to view with skepticism such statements as

> Both federal and provincial governments should explore the possibility of creating new mechanisms for supplying capital to new and small companies ... In the last resort it may even be necessary to insure the loans made by private venture capital firms ... [10]

> Start-up funds are in seriously short supply in Canada. This applies to all start-ups, but especially for new, technology-based ventures.[11]

10 Science Council of Canada, Report No. 15 (1971, 31).
11 Grasley (1968, 27).

Entrepreneurs are a true natural resource ... who will have an inordinate influence on the formation of new enterprises and hence the economy, provided they are given financial support and the proper environment in which to flourish. (32)

... The main problem is the shortage of capital and of good management advice. The Committee thinks two new programs should be initiated by the government to plug these gaps.

The first is a special loan scheme with lower interest rates ... It should be designed for small and medium-sized firms that find it difficult or impossible to find venture or working capital on reasonable terms. The program should also include guaranteed loans.

The second is a special equity capital fund for the same general purpose, chiefly for new technology-based enterprises ... The Committee has found that the private financial sector is particularly weak in Canada and that a public fund might not only fill a gap but help existing companies to become more dynamic and progressive.[12]

Advocates of public support of new technical enterprises must demonstrate that the market has failed to allocate sufficient resources to such ventures. They seldom do so. Neither the fact that many risky ventures are unable to obtain finance at conventional rates of interest nor the claim that relatively more risky ventures are undertaken in other countries is indicative of market failure. Nor is the often cited 'unwillingness of Canadians to bear risk' indicative in itself of a failure of the market. The payment required to induce individuals to bear risk is a cost which must be taken into account in assessing any venture. This is true whether the investment decision is made by the state or in the market.[13] In terms of its consequences, ignoring the cost of risk bearing is the same as ignoring any other cost. It leads to an allocation of resources which reduces real income.

Grasley (1975) has argued that the tax system contains provisions which bias the market allocation of resources away from R&D (11-12). The taxation of income does have the general effect of reducing both investment and the supply of factor services. None of the provisions of the tax system mentioned by

12 Senate Committee on Science Policy (1973, 577-8).

13 That the state cannot disregard the cost of non-diversifiable risk in its investments decisions is the principal conclusion of the analysis presented above.

Grasley has the effect of biasing the allocation of resources away from R&D in particular. Indeed, if as Hirshleifer (1971) has theorized, a large portion of the return to inventive effort comes in the form of capital gains, the relatively favourable tax treatment accorded capital gains, together with the incentives listed in Section 3.1, biases the market allocation of resources towards R&D.

It has also been argued that Canada's centralized and cartelized banking system has biased the market allocation of resources away from risky ventures in general and R&D in particular. One expects that a banking cartel will indeed have a greater spread between deposit and loan rates on loans of all risk classes than would a competitive banking system. Some theorists argue that, in addition, a banking cartel would maintain a less risky asset portfolio. Against this, there is the argument that the best way for a cartel member to cheat on an interest rate agreement is to grant a riskier loan at the same interest rate. The issue is clearly unresolved and merits additional investigation. It is issues such as this that those who argue for government support of R&D (or any other activity) on the grounds of imperfect capital markets should be investigating.[14]

1.4 OTHER REASONS FOR STATE INTERVENTION

Participants in the debate on science policy have suggested a number of reasons other than those adduced in the previous section, for the state to involve itself in scientific research and development. These reasons can be classified and are discussed under the following headings: (1) growth and the impending scarcity of natural resources, (2) employment opportunities for scientists and engineers, and (3) foreign ownership and the truncation of Canadian firms.

1.4.1 *Growth and the impending scarcity of natural resources*

In its report the Senate Committee on Science policy concluded that technological innovation is the 'mainspring' of economic growth and that to undertake such innovation Canada requires 'an adequate level of effectively managed R&D activity ... '[15] That is, R&D should be encouraged because it causes economic growth. The Committee goes on to cite supportive empirical evidence on the relationship between R&D and economic growth.

14 A perceptive discussion of imperfections in the capital market and, in particular, the practice of labelling the costs of operating a market as 'imperfections'. See G.J. Stigler (1968, 113-22).

15 Senate Committee on Science Policy (1973, 489).

This line of argument does not provide any additional reason for state involvement in R&D. The allocation of additional resources to scientific research and development or to any other investment activity (education, road building, etc.) contributes to economic growth if that investment yields a positive social rate of return. Maximization of the rate of growth consistent with a given level of saving requires that society choose the set of investments (which may or may not include investments in R&D) with the highest social rates of return. Normally, it will be in the interest of individuals and firms to choose such a set. If the returns to some investments are not fully appropriable, the allocation by the market of savings among alternative investments will not be that which results in the maximum attainable rate of growth. In this case, the government may intervene to correct the inappropriability problem. This case was discussed in detail in Section 1.2.

To summarize, all successful investments cause growth. The empirical link between R&D and economic growth (which has yet to be established in this country) does not in itself justify state intervention to support R&D. It must also be established that, at the margin, the social rate of return to R&D exceeds that yielded by alternative investments. This the Senators have not done.[16]

The Senate Committee pursues the 'growth' issue further, arguing that Canada has achieved growth in the past through the exploitation and export of natural resources. Since these resources will eventually be exhausted, this strategy cannot be continued. The appropriate new strategy, it is argued, is to rely more on technology and less on resource exploitation for future growth. The implicit policy recommendation is that the state undertake, first, to reduce the rate of exploitation of natural resources and, second, to increase the value of resources allocated to R&D.

To comment properly on this recommendation, it is necessary to understand the nature of the decision to conserve non-renewable natural resources. The latter are, along with machines, roads, and knowledge, part of society's stock of capital. This stock, combined with labour services, yields a flow of goods and services over time. Given an initial endowment of natural resources, society chooses the time distribution of goods and services to be derived from it. The growth process entails the curtailment of the present consumption of goods and services so that consumption in some future period can be increased. Growth requires investment which is, in effect, an exchange of present for future consumption. One method of exchanging present for future consumption is to

16 For a study that demonstrates the excess of the marginal rate of return to R&D over other types of capital employed in U.S. agriculture and thus provides a rationale for additional R&D spending, see Zvi Griliches (1964).

forego the use of natural resources now in order that their products may be consumed at a future date. Conservation is, therefore, an investment that yields a return in terms of increased consumption at some future date. Alternatively, natural resources may be used to produce other forms of capital which will in turn, result in increased consumption at some future date. This is also an investment.

Conservation, R&D, the construction of roads or machinery, and education are thus alternative types of investment. There is no inherent reason to prefer one of these investment alternatives over the others. Individuals and firms will presumably choose among them on the basis of their respective rates of return. State intervention can be justified only on the grounds that the choices of individuals and firms are not optimal from a social point of view. The specific type of intervention recommended by the Senate Committee is justifiable only if, at the margin, the social return to both R&D and conservation is greater than that yielded by alternative investments. The reasons for believing that this is true of R&D were outlined in Section 1.2. Some have argued that it is also true of conservation, although on the theoretical level the issue is unresolved.[17]

In summary, Canadians may have under- or over-invested in conservation. If so, intervention in natural resources markets may be justified. Similarly, intervention to encourage R&D or some other type of investment may be justified. These decisions can be made independently. Canadians should be aware that conservation and research are not, as the Senators seem to argue, complimentary components of a new growth strategy. They are substitutes. An increase in the amounts of both R&D and conservation undertaken necessitates a reduction in either other types of capital formation or consumption or both.

1.4.2 *Employment opportunities for scientists and engineers*

It has been argued that public support of R&D is warranted because it will help to provide job opportunities for science and engineering graduates. The Science Council (1971) has argued that

> The general lack of new employment opportunities in manufacturing has serious implications for scientists and engineers, particularly since we have increased our output of these graduates three-fold in the last few years ...

17 For a theoretical examination of this issue, see William D. Nordhaus, 'Markets and appropriable resources,' in Michael S. Macrakis, ed. (1974). The practical question of the extent to which the tax system and price controls distort investment decisions against conservation and in favour of physical capital formation in itself worthy of detailed study.

It should not be concluded that all those who have chosen training in science and technology should be entitled to employment in the field of their choice. The well-being of the nation requires that an effective use be made of highly trained people in all categories. However, public credibility will inevitably be strained if funds continue to be used to support and promote scientific education unless an effective use can be made of these graduates. (19)

The Select Committee on Economic and Cultural Nationalism (1975) expressed similar sentiments:

If young Canadian scientists and engineers desire careers in mainstream research and development in the automobile industry, it would be futile to try to do so in Canada ... This means that potentially exciting career paths are severely limited or, in many individual cases, cut off entirely. It means that this avenue is largely unavailable to capitalize on and recoup the substantial public and private investment in advanced technical education and supporting facilities, though, as noted, the benefits of education may be as substantially secured in the application of imported technologies as in developing new ones. (54)

It is difficult to find good arguments in favour of policies designed to provide jobs offering 'exciting career paths' or simply validating the educational decisions of a select group of people. The maximization of the return to the resources invested in their education requires that scientists and engineers work where they are valued most highly by society. This may or may not be in R&D. If, by creating additional jobs in R&D, the government bids scientists and engineers away from occupations in which their services are valued more highly, aggregate real income is reduced as are the returns to a scientific education. The Economic Council of Canada (1968) reached a similar conclusion.

At least to some extent, alternative employment opportunities can be developed for such people – for example in basic research, applied research and development, production, engineering, management or teaching. Thus the social cost of using a scientist in, say, R&D activity is the 'loss' of what he would have produced in some alternative employment. This 'loss' may be greater under certain conditions – for example where there is a great shortage of teachers – than the gain from his employment in R&D. (47)

Under these circumstances Canadians must balance the psychic income, if any, they derive from having more of their countrymen doing R&D against the real income (command over goods and services) lost as a result.

If, because of the inappropriability of the returns to scientific research, the income of a scientist is less than his value to society, the income and employment opportunities observed in the market will not lead a science or engineering graduate to the area of endeavour which is of the highest value to society. Intervention to equate the social and private returns to R&D will correct this problem. This type of intervention was discussed in detail in Section 1.2.

It may also be the case that a given group of scientists or engineers have virtually no employment alternatives. That is, their employment on an R&D project does not bid them away from other jobs and is therefore 'costless' to society. R&D projects could then be subsidized to the extent of the wages of scientists and engineers employed. Aggregate real income would be increased by such a policy.

A situation such as the above is unlikely to occur in practice. Moreover, it is a distinctly short-run situation. The employment of a group of scientists and engineers who have already been trained and for whose training society has, in the extreme case presented here, no use other than R&D, is being subsidized. Those either in or about to enter training will have alternative employment opportunities. It is clearly in society's interest that they alter their training program in order to pursue them. Creating jobs in R&D is not the way to send them the signals to do so. Thus subsidization of the employment of scientists and engineers must be a very temporary measure and must be seen to be so.

A slightly different set of issues involved in the alternative to R&D employment is emigration. The effect of the emigration of scientists and engineers on the income of those left behind has been analysed by Grubel and Scott (1966), who wrote

> According to the traditional analysis of the migration of labour, the departure of a person normally raises the long-run average income of those people remaining because it results in an increase in the nation's capital-labour ratio. In the case of the migration of a highly skilled person, however, this conclusion does not hold if the human capital embodied in the emigrant is greater than the country's total per capita endowment of human and physical capital, assuming perfect substitutability of the two forms of capital in the long-run. In this case, the emigration of a highly skilled person reduces the total income to be distributed among the residents of a country and it follows that in societies where this distribution occurs through planning or other non-market means the remaining population suffers a reduction in welfare.
>
> In a market economy where persons are paid their marginal product, however, such a reduction in per capita income is only a statistical phenomenon which has no influence on the welfare of the remaining people: the emigrant

removes both his contribution to national output and the income that gives him a claim to this share so that all other incomes remain unchanged ...

Thus it follows that in a market economy any effects that the emigration of a highly skilled person is likely to have on the welfare in short-run adjustment costs or in market failure. (270)

The emigration of a scientist results in the loss to Canada of the value of his output less his claim on the goods and services produced by other Canadians. If one allows for the existence of income taxes, this amounts to the income tax payments of the scientists less the value of any government services (not public goods) he consumes. The loss to Canada through emigration then, is zero or a positive value, the size of which depends on the extent to which the value of the emigrant's services exceeds his claims on the Canadian economy.

Are there any circumstances under which R&D should be subsidized simply to keep scientists in Canada? Consider a project for which the only resource input is the effort of scientists. The scientists produce new information for which Canadians are willing to pay, in present value terms, one million dollars. If they are not engaged in this project they will emigrate. If the present value of the scientists' wages is one million or less, the project is clearly desirable and will normally be undertaken. No intervention of the type being discussed here is necessary. If, for some reason, the wage bill exceeds one million (say \$1.2 million), the project would not normally be undertaken and the scientists would leave. Is it in the interest of the remaining Canadians to subsidize the project and prevent the emigration? It is not. If the project is undertaken, Canadians will transfer claims on goods and services valued at \$1.2 million (less scientists' taxes less government services consumed) to scientists in return for information they value at one million dollars. Canadians are clearly better off to allow the scientists to emigrate.

The emigrating scientist may have been educated at public expense with the implicit provision that the public be repaid by subsequent taxation of his income. With emigration there is no repayment. This does not imply, however, that R&D projects should be subsidized to keep science graduates in Canada so they can 'pay' for their education. The educational decision has been made and the costs incurred are sunk. As shown above, the R&D subsidy only imposes further costs on the balance of the population. In an attempt to salvage one erroneous decision, Canadians would be reducing their real incomes even further. If the costs of a scientific education are to be recovered from its recipient, this can be done effectively by imposing explicit repayment provisions on him, binding regardless of his ultimate nation of residence.

1.4.3 *Foreign ownership and truncation*

Many of those who argue that Canada should allocate additional resources to R&D would agree with the evaluation of the growth, conservation, and employment opportunities arguments presented above. They would agree that resources should be devoted to the uses in which they earn the highest social rate of return and that the state has a role in equating social and private rates of return so that the allocation decisions which are in the interest of individuals and firms are also in the interest of society. They would go further, however, and argue that there are circumstances under which the predicted response to market signals (as modified by state action) will not occur. Quite simply there are profitable opportunities which will not be exploited. Activities, such as R&D, which would qualify as an efficient use of Canadian resources are not undertaken. It has been claimed that foreign owned firms centralize R&D facilities in their home country and import technology that could be produced as efficiently in Canada. Foreign owned firms, it is claimed, ignore or do not correctly assess relative costs and, as a result locate R&D facilities in the 'wrong' country.

This is the conclusion reached by the Ontario Legislature's Select Committee on Economic Nationalism (1975). After hearing testimony from foreign owned firms that R&D must be centralized to enhance 'co-ordination and cross-stimulation among research and design personnel' and that it must be centralized in the home country so that marketing and production management may be kept 'in close touch with technological developments, and ... have ready access to the R&D personnel and facilities for technical advice ... ' the Committee concluded that it was ' ... not satisfied that these considerations provide systematic justification for the general failure of foreign owned enterprises to locate significant R&D facilities in Canada ... ' (52)

As a remedy the Committee recommended that the Canadian operations of foreign firms be 'reviewed' periodically with a view to securing undertakings from such firms to do more R&D or different kinds of R&D. (90-97)

In evaluating the Committee's analysis one must first examine its empirical foundations. Is it the case that, under similar circumstances, foreign owned firms spend less on R&D in Canada than do Canadian owned firms? If it is not, the Select Committee's conclusion that foreign owned firms are ignoring market signals and conducting R&D abroad merely because they are foreign owned is unwarranted. Foreign ownership per se is not responsible for the 'underdevelopment' of Canadian industrial R&D capacity and there would appear to be little scope for bargaining with foreign owned firms over their R&D expenditures. If, however, foreign owned firms spend less on R&D in Canada than do domestically

owned firms facing similar circumstances, one can infer either that there are economies to be gained in locating R&D facilities near headquarters (as was claimed in testimony before the Select Committee) or that one set of firms is ignoring relative costs when deciding upon the location of R&D facilities. The latter outcome is unlikely, but it does leave some scope for the type of bargaining advocated by the Select Committee.

The existing evidence, the most complete and competently assembled of which was reported by Safarian (1966, 1969), does not support the Committee's conclusion. Safarian compared the R&D expenditures of 160 foreign and 96 domestically owned firms for the year 1959. He found no difference between them in R&D expenditures expressed as a proportion of sales.[18]

Our empirical examination is based on a sample of 256 observations taken over the period 1967-71 on 80 firms, 57 of which are foreign owned. Following the practice of Statistics Canada (annual), we define a firm to be foreign owned if fifty-one per cent of its equity is held by foreign nationals. For the most part we define annual R&D expenditures as the total R&D expenditures reported by the firm less any R&D done under contract, less R&D incentive subsidies, less payments for R&D conducted extramurally. This is the amount of R&D conducted in Canada and financed by the firm itself.

We also investigate the effect of foreign ownership on expenditures by the sample firms for R&D which is conducted extramurally. Expenditures on extramural R&D are further subdivided into that which is conducted domestically and that which is conducted abroad. A finding that foreign owned firms spend less on domestically produced knowledge and/or more on knowledge produced

18 Safarian (1969, 52) reports ... 'If one confines one's attention only to manufacturing firms, the safest conclusion would appear to be that there is no statistical significance between the research efforts of the two sets of firms.'

19 In the case of population regression model (1) in the text, it can easily be shown that

$$\hat{a}_1 = \bar{R}_F - \bar{R}_D$$

and

$$S^2_{\hat{a}_1} = 1/(n_F + n_D) \sum^{n_F + n_D} (R_{it} - \bar{R})^2 \; (1/n_F + 1/n_D),$$

where $\bar{R}_F$ = sample mean R&D expenditures of foreign owned firms,

$\bar{R}_D$ = sample mean R&D expenditures of domestically owned firms,

n_F = number of foreign owned firms in the sample,

n_D = number of domestically owned firms in the sample.

In this case a test of the null hypothesis that $a_1 = 0$ is equivalent to a test of the null

abroad than do domestically owned firms would also be supportive of the Select Committee's conclusions.

We begin our empirical examination with a test of the null hypothesis that the average of the R&D expenditures of foreign owned firms does not differ from that of domestically owned firms. We employ regression analysis with dummy variables with this and all other tests[19]. The model is written as

$$R_{it} = a_0 + a_1 D_i + e_{it} \tag{1}$$

where R_{it} = R&D expenditures (as defined in the text) of the ith firm during year t.

D_i = 1 if the ith firm is foreign owned,
= 0 otherwise,
e_{it} = a random disturbance.

An estimate of (1) appears as equation (1) in Table 1. At the 99 per cent confidence level, we can reject the null hypothesis in favour of the alternative hypothesis that the average R&D expenditures in Canada of foreign owned firms is less than that of domestically owned firms.

This test is obviously naive. It does not standardize for differences among firms other than those which are due to ownership. Foreign owned firms may be concentrated in industries in which the returns to R&D are relatively low. In this case the above test attributes to ownership an effect which is due to the industry in which the firm operates.

Foreign ownership may be concentrated in a particular size class of firms. If firms in that size class spend less on R&D than do firms of other sizes, the above test will ascribe to ownership an effect due to firm size.

These defects can be remedied by testing the null hypothesis that, given the sales revenue of each firm and the industry in which it operates, the average of

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hypothesis that $\bar{R}_F$ and $\bar{R}_D$ come from populations with identical means. The test statistic calculated from the above information is correct, provided the variances of the two populations can be assumed equal. This assumption is equivalent to the assumption of homoskedastic residuals in regression analysis. Where an F-test indicates that the variances of the underlying populations are unequal, that is, that the residuals are heteroskedastic, models (1) and (2) must be transformed. The assumptions made here regarding the nature of the heteroskedasticity are described in detail in Kmenta (1971, 261-4). The appropriate transformation follows from these assumptions.

TABLE 1

Definition of dependent variable	Independent Variable			
	D_i	$D2_i$	S_{it}	df
1 R&D expenditures within the firm, less contracts and subsidies	−2,132.7 (3.19)	–	–	253
2 Same as (1)		−101.9 (3.01)	.022 (13.17)	234
3. Expenditures for R&D done extramurally within Canada		– 25.22 (3.04)	.0005 (12.22)	199
4 Expenditures for R&D done extramurally abroad		48.3 (1.37)	.0002 (3.26)	130

NOTE: t-ratios in brackets below coefficients. Industry intercepts are not reported.

the R&D expenditures of foreign owned firms does not differ from that of domestically owned firms. The appropriate model is then written

$$R_{it} = \sum_{j=o}^{K} b_j D1_{ij} + b_{K+1} D2_i + b_{K+2} S_{it} + u_{it}, \tag{2}$$

where $D1_{ij}$ = if the ith firm is operating in the jth three-digit industry,

= 0 otherwise,

$D2_i$ = if the ith firm is foreign owned,

= 0 otherwise,

S_{it} = Sales revenue of the ith firm during period t,

u_{it} = random disturbance.

The estimate of (2) appears as equation (2) in Table 1 (industry intercepts are not reported). At the 99 per cent confidence level the null hypothesis can be rejected in favour of the alternative hypothesis that, given size and industry differences, the average R&D expenditures of foreign owned firms are less than those of domestically owned firms.

This test, while it represents a distinct improvement over our initial one, is inadequate in several respects. First, our standardization for the effect of firm

size on R&D expenditures is correct only if the R&D-firm size relationship is linear.[20] If it is non-linear, we may be ascribing to ownership an effect that is due to this non-linearity. Second, a number of studies have found that, given firm size, R&D expenditures increase with current or past profits or with internal cash flow.[21] If foreign owned firms of a given size are less profitable or have smaller internal cash flows, we could again be attributing to ownership an effect that is due to these factors. Third, equation (2) tests the hypothesis that *on average* R&D expenditures of foreign and domestically owned firms differ. The effect of foreign ownership on R&D expenditures may itself differ from industry to industry. The same will be true of sales revenue.

The foregoing implies that the effect of ownership on R&D expenditures can be investigated properly only within the context of a fully specified model of the determinants of R&D expenditures. Moreover, this model must allow for differences among industries and between ownership classes in the effect of each independent variable on these expenditures. A model that suits this purpose has been estimated by Howe and McFetridge.[22] It can be written as

$$R_{it} = c_0 + c_1 S_{it}^2 + c_3 S_{it}^3 + c_4 P_{it} + c_5 A_{it} + c_6 G_{it} + v_{it}, \tag{3}$$

where R_{it} = R&D expenditures (as defined above) of the ith firm during year t,

S_{it} = sales of the ith firm during year t,

P_{it} = profits (after taxes but before the deduction of R&D expenditures) of the ith firm during year t,

A_{it} = depreciation charges of the ith firm during year t,

G_{it} = government R&D incentive grants received by the ith firm during year t,

v_{it} = a random disturbance.

This model was estimated for each of the electrical, chemical, and machinery (two digit) industries using the sample described above. The c_j were allowed to vary between ownership classes and over time. Application of the usual analysis of covariance technique described in Johnston (1972) revealed that the c_j differed substantially between ownership classes and very little over time. Thus, the

20 This assumption is implicit in the test conducted by Safarian (1969, 52).

21 See, for example, Grabowski (1968).

22 For a discussion of model (3) and details of its estimation, see Howe and McFetridge (1976) and Section 3.3 of this study.

final estimates of the c_j reported by Howe and McFetridge and in Table 6 of this study differ between foreign and domestically owned firms for most (but not all) values of c_j.

If we set each of the independent variables equal to a given value, the sample mean, for example, the $\hat{c}_j$, can be used to provide both point and interval estimates of the R&D expenditures of both foreign and domestically owned firms in each industry. We then compare the predicted R&D expenditures of each group of firms.

This test is superior to tests based on models (2) and (3) in several respects. It allows for a non-linear R&D-sales relationship. It holds constant interfirm differences in profits, depreciation charges, and R&D incentive grants. It allows all coefficients, rather than merely the intercept, to differ between foreign owned firms and domestically owned firms. It allows all coefficients to differ across (two digit) industries rather than allowing the intercept alone to differ across (three digit) industries. Although it proves unnecessary, this approach also allows all coefficients to differ from year to year.

If each independent variable in model (3) is set equal to its sample mean and substituted into the estimates of (3) reported in Table 6, we obtain a predicted level of R&D expenditures for both domestically owned and foreign owned firms. This value can be written as

$$x = E(R/\bar{S}, \ \bar{S}^2, \bar{S}^3, \bar{P}, \bar{A}, \bar{G}),$$

the expectation of R given that each of the independent variables is set equal to its mean. A confidence interval of x can be obtained in the manner described by Kmenta (1971, 363-4).[23]

In the case of the electrical industry we find Pr $(5{,}974 < x < 6{,}906) = .95$ for domestically owned firms, while Pr $(1{,}018 < x < 1{,}550) = .95$ for foreign owned firms. The confidence intervals do not overlap. When foreign and domestically owned firms face identical environmental circumstances, the latter spend more on R&D.

Turning to the chemical industry, one finds that Pr $(1{,}094 < x < 1{,}390) = .95$ for domestically owned firms while Pr $(474 < x < 646) = .95$ for foreign owned firms. Again, given similar environments, the Canadian R&D expenditures of domestically owned firms exceed those of foreign owned firms.

Finally, in the case of the machinery industry, one finds Pr $(356 < x < 676) = .95$ for domestically owned firms, while Pr $(561 < x < 833) = .95$

23 Since all independent variables are set equal to their respective means, the estimated standard error of $E(R_{it})$ reduces to $S/\sqrt{n}$, where S is the standard error of estimate.

for foreign owned firms. All else being equal, there is no difference in the Canadian R&D expenditures of foreign and domestically owned firms.

These results confirm, in part, the results of the initial, simpler tests. The latter implied that, taken together, foreign owned firms spend less in Canada on R&D than do domestically owned firms. The more sophisticated tests reveal that this conclusion is valid for two of the three industries examined.

In the case of the electrical and chemical (two digit) industries then, there is at least an empirical foundation for the analysis of the Special Committee. The Canadian R&D spending of foreign owned firms is less than half that of domestically owned firms facing similar circumstances. This could reflect the existence of economies in locating R&D facilities near headquarters or the ignorance of foreign owned firms of the real advantages of locating R&D facilities in Canada or the ignorance of domestic firms of the advantages of locating R&D facilities abroad. Under the second set of circumstances there may be legitimate grounds for bargains which result in a shift to Canada of a firm's R&D efforts. This rather weak conclusion is all this analysis yields in terms of policy implications. It says nothing about the total value of resources which Canada should devote to acquiring new knowledge, either imported or domestically produced, or about the terms on which imported knowledge should be acquired. The latter issue was the legitimate concern of both the Select Committee and the Gray Report (1972, 128-35) and is worthy of further study.

To this point we have considered only R&D carried on within the firm and within Canada. The analysis can and should be extended to cover expenditures for R&D conducted extramurally.

An estimate of model (2) where the dependent variable is now annual expenditures for R&D conducted outside the firm but within Canada appears as equation (3) in Table 1. One can reject at the 99 per cent confidence level the null hypothesis that these expenditures do not differ between ownership categories in favour of the alternative hypothesis that these expenditures are, on average, greater among domestically owned firms. This reinforces the conclusions reached regarding R&D conducted within the firm. Taken together, domestically owned firms spend more on R&D conducted domestically.

An estimate of model (2), where the dependent variable is defined as annual expenditures on R&D conducted both extramurally and outside Canada, appears as equation (4) in Table I.[24] In this case, the average expenditure of foreign

24 R&D expenditures here include payments by Canadian firms for R&D done by foreign affiliates. Payments by Canadian subsidiaries of a multinational firm for R&D done by subsidiaries of the same firm which are located in other countries would fall in this category. Royalty payments are not included.

owned firms is greater than that of domestically owned firms. The difference is significant, however, only at significance levels in excess of seventeen per cent. This result provides only weak support for the Select Committee's view of the world.

Taken as a whole the results are broadly supportive of the inferences made earlier. There may be economies in centralizing R&D at the headquarters of the firm. If such economies do not exist, it is possible that either domestic or foreign firms are ignoring relative cost considerations in locating their R&D facilities. No inference regarding the total R&D expenditures of either group of firms can be made on the basis of these results.

2

Guidelines for the administration of subsidies

2.1 INTRODUCTION

In Section 1.2, it was demonstrated that the subsidization of scientific R&D could be justified on strict allocative efficiency grounds. That is, the subsidization of R&D has the effect of increasing the value of the goods and services that can be produced with a given resource endowment. In the following sections, the criteria to be used in the administration of such subsidiaries are discussed. In particular, an attempt is made to answer the following questions:

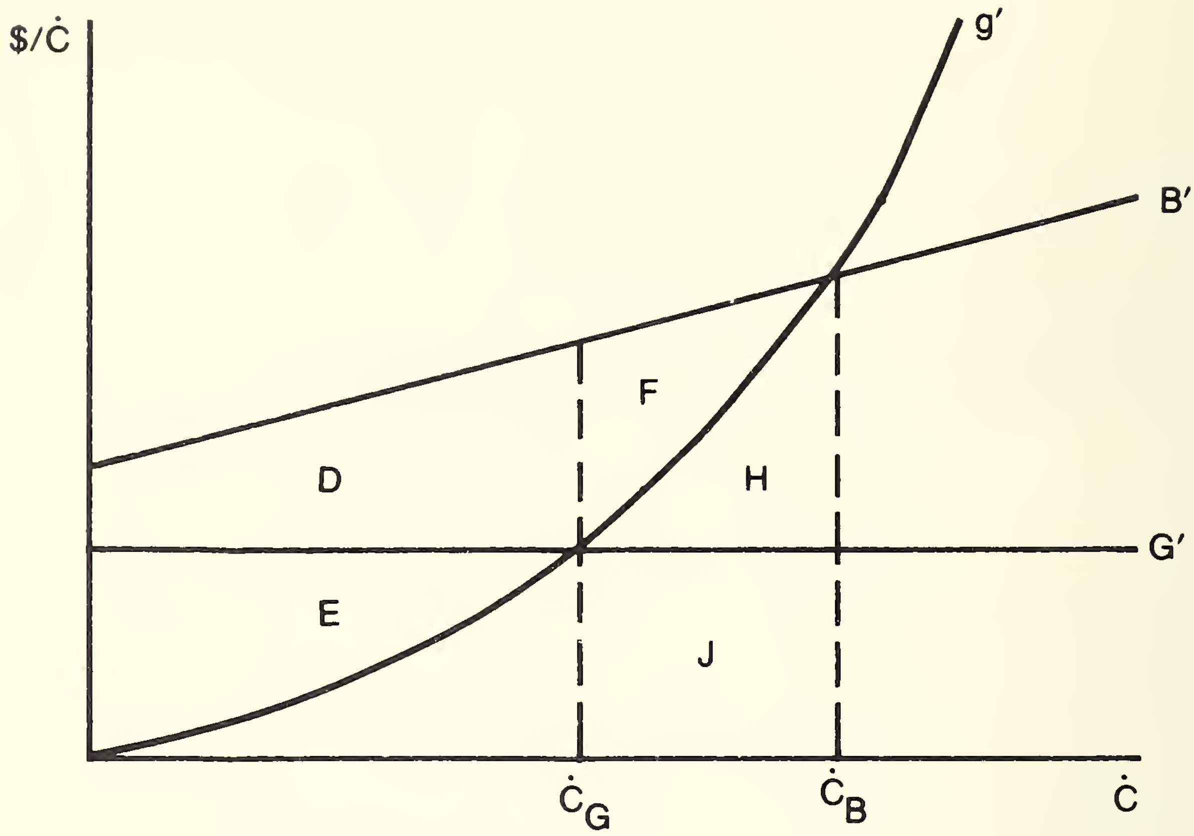
a Should the administrators discriminate between foreign and domestically owned firms in the awarding of subsidies?
b Should recipients of subsidies be required to exploit the results of their R&D in Canada?
c Should administrators discriminate between exporting and non-exporting firms in the administration of subsidies?
d How big should the subsidy be?
e What information should be required of subsidy applicants?

The discussion of these questions will employ the theoretical framework developed in Section 1.2.

2.2 FOREIGN OWNERSHIP AND THE RETURNS TO R&D: IMPLICATIONS FOR THE ADMINISTRATION OF SUBSIDIES

In this section, we investigate the effect on the social return to resources allocated to R&D of differences in the nationality of the ownership of the rights to

Figure 4



the new knowledge produced. It is shown that under certain circumstances, the return to resources allocated to R&D is greater when the rights to its results are domestically owned. It is also shown, however, that there are, in general, no grounds for discriminating on the basis of ownership in the awarding of R&D subsidies.

Consider again the model employed in Section 1.2. As is illustrated in Figure 1, a process innovation shifts the long-run supply function for good X downward to S'. If the owners of the rights to the innovation are granted a patent T periods in duration and set royalties approaching $(P_1 - P_2)$ per unit of X produced, the present value of their gross income (gross private benefit) is

$$G = P_1 Q_1 \; \dot{C}(1 - e^{-rT})/r. \tag{1}$$

The marginal private benefit of a change in the rate of cost reduction is

$$G' = P_1 Q_1 \,(1 - e^{-rT})/r. \tag{2}$$

After the expiry of the patent the process innovation is freely available to all X producers and, as a result, the price of X is bid down to P_2. If the rights to the innovation are domestically owned, the gross social benefit resulting from it is the sum of the private benefit and the increase in consumers' surplus which occurs after the expiry of the patent. It can be written as

$$B = (P_1 Q_1 \dot{C} + \tfrac{1}{2} P_1 Q_1 \epsilon \dot{C}^2 e^{-rT})/r. \qquad (3)$$

The marginal social benefit of a change in the rate of cost reduction is

$$B' = (P_1 Q_1 + P_1 Q_1 \epsilon \dot{C} e^{-rT})/r. \qquad (4)$$

The marginal R&D cost of a change in the rate of cost reduction is again assumed to be an increasing function of the rate of cost reduction desired. Thus

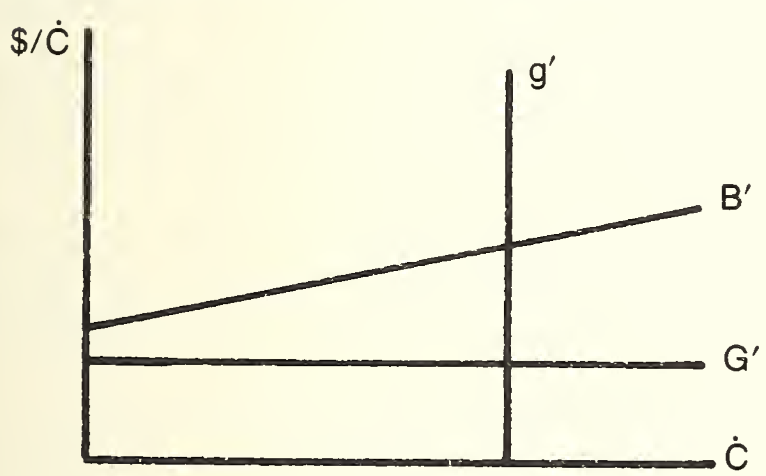
$$R = g'(\dot{C}). \qquad (5)$$

Functions (2), (4), and (5) are graphed in Figure 4.[1]

Maximization of the net private benefit of R&D requires that the rate of cost reduction be such that the marginal private benefit equal the marginal R&D cost of a change in the rate of cost reduction. This rate is shown as $\dot{C}_G$ in Figure 4. It will be chosen regardless of the nationality of the ownership of the rights to the innovation. The present value of the net private benefit (economic profits) accruing to the owners of these rights is given by area E in Figure 4.

The net social benefit resulting from the innovation depends crucially on the nationality of the ownership of the rights to it. If the latter are foreign owned the net private benefit, E, accrues to foreigners and must be treated as an additional cost.[2] Net social benefit is then given by area D in Figure 4. If the

1 It was the opinion of the authors of the Economic Council of Canada's 'Report on Intellectual and Industrial Property' (1971) that the rate of invention was largely insensitive to any incentive provided by the Canadian patent system. In the present context this implies a vertical $g'(C)$ function which is illustrated below.



In this environment the optimal patent term is zero periods and there is no scope for the subsidization of R&D.

2 Foreigners have a claim on Canadian goods and services with a present value given by area E. When they choose to exercise it, Canadians must forego consumption of goods and services of a similar value.

rights to the innovation are domestically owned, net social benefit includes any privately appropriated surplus and is therefore given by areas D and E in Figure 4. Thus, to the extent that any economic profits resulting from an innovation accrue to foreigners, the social net benefit resulting from that innovation is reduced.

As can be seen from expressions (2) and (4) and Figure 4, an increase in the patent term results in an upward shift of G', while B' is shifted downward and reduced in slope. As the patent term approaches infinity, G' approaches B', the net social benefit resulting from a foreign owned innovation approaches zero and the net social benefit resulting from the same innovation domestically owned approaches

$$\int_0^{\dot{C}_G} [(P_1 Q_1 / r) - g'(\dot{C})] d\dot{C}$$

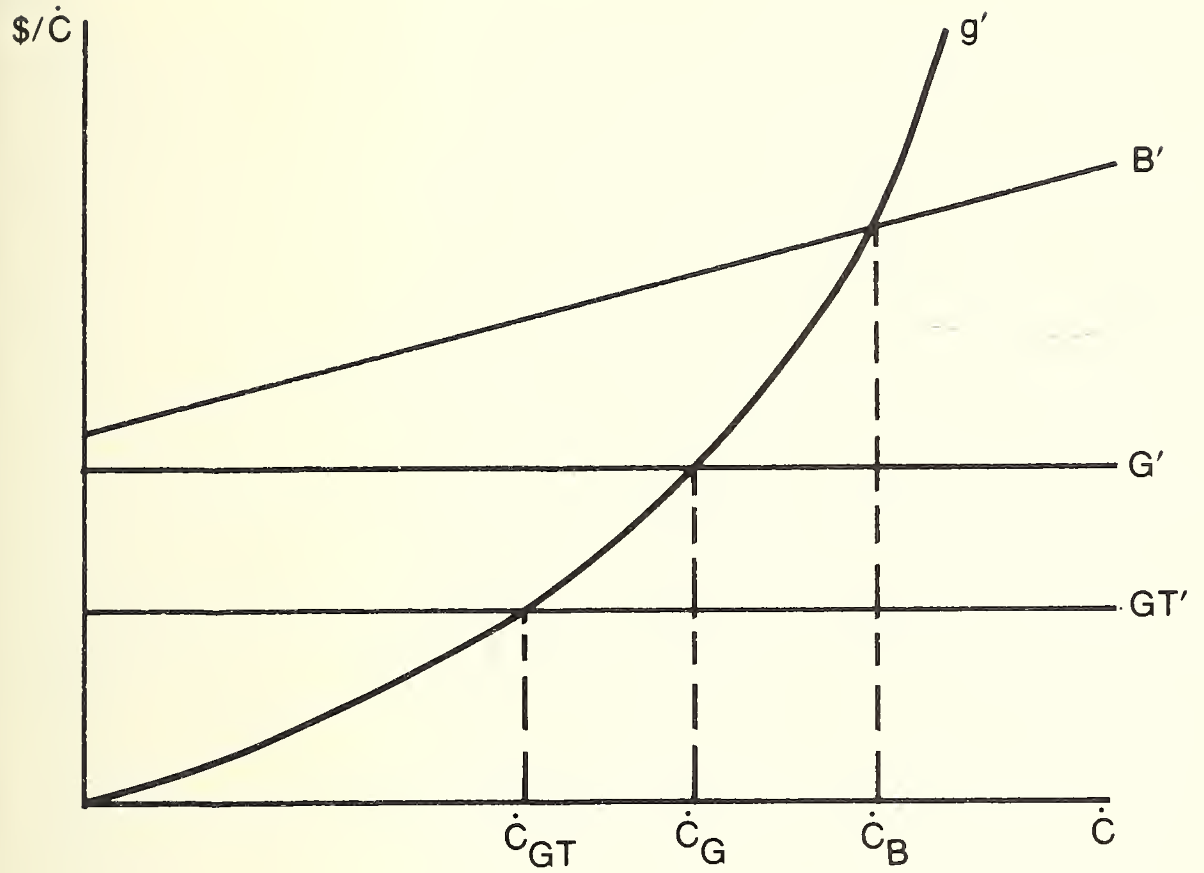
which exceeds zero. Thus, the longer the patent term the greater is the net social benefit occurring under domestic ownership relative to that which occurs under foreign ownership.

The rate of cost reduction which maximizes private net benefits, C_G, is less than that which would maximize social net benefits, $\dot{C}_B$. This is true regardless of ownership and for patent terms of a finite duration. A subsidy with a present value given by area H in Figure 4 is sufficient to induce additional resources with a value of $H + J$ dollars into R&D and hence to achieve a rate of cost reduction which is optimal from a social viewpoint. The present value of the increase in net social benefit or welfare resulting from the subsidy is given by area F[3]. Both the appropriate subsidy and the increase in net social benefit, H and F respectively, are the same regardless of the nationality of the ownership of the rights to the innovation. The reason for this is that the subsidy advocated is just equal to the opportunity cost of the additional R&D resources employed. Since none of the increase in net benefit produced by the latter is privately appropriable, the issue of ownership becomes irrelevant.

To summarize, while the post-subsidy net social benefit under domestic ownership, $D + E + F$, exceeds that obtained under foreign ownership, $D + F$, the incremental net social benefit resulting from the subsidy is the same regardless of the nationality of the ownership. At the margin, therefore, there are no grounds for discriminating between applicants for subsidies on the grounds of ownership. There are, however, grounds for scrutinizing the subsidy requests of

3 The usual second best caveat holds. The welfare gain is unambiguous only if the amount paid for additional R&D resources reflects their opportunity cost. Distortions in the sectors from which these resources are drawn may result in their opportunity cost exceeding H and J. The increase in net social benefit due to the subsidy must be reduced to this extent.

Figure 5



foreign owned firms more thoroughly. The reason for this is that any subsidy payment to a foreign owned firm in excess of the opportunity cost of the additional R&D resources required is itself a cost and, as such, reduces net social benefit. An over-payment to a domestically owned firm has no effect on net social benefit provided it does not exceed $B' - G'$ dollars per percentage point of cost reduction achieved.[4]

The introduction of income taxes does not change the conclusion reached above. If, for example, the owners of the innovation must pay taxes at rate t on royalty income the marginal private benefit function becomes

$$GT' = (1 - t)\, P_1 Q_1 \; (1 - e^{-rT})/r, \tag{6}$$

which lies below G' for any positive tax rate. As is illustrated in Figure 5, the profit maximizing rate of cost reduction is reduced. The deviation between the

4 The 'excess' subsidy has no efficiency implications in the case of the domestically owned firm because it is not excessive at the margin. At $\dot{C}_B$ (Figure 4) the minimum and maximum allowable per unit subsidies coincide. To the right of $\dot{C}_B$ a per unit subsidy of $g' - G'$ entails a social loss of $g' - B'$ per percentage point of cost reduction achieved. The loss due to the overallocation of resources to R&D is the same whether the subsidy recipient is foreign or domestically owned. I am indebted to Professor Steven Globerman for bringing this matter to my attention.

private and social optima is increased and with it the scope for and returns to subsidization.

The greater the tax rate, the greater is the net social benefit occurring under foreign ownership relative to that which occurs under domestic ownership. To generalize, the higher the tax rate or the shorter the patent term, the smaller is the relative effect of foreign ownership and the less important it becomes as a policy issue.

2.3 RESTRICTIONS ON THE LOCATION OF PRODUCTION: IMPLICATIONS FOR THE ADMINISTRATION OF SUBSIDIES

Present Canadian subsidy programs contain a provision requiring that any inventions resulting from subsidized R&D projects be worked on or manufactured in Canada.[5] This provision is apparently designed to 'create jobs' manufacturing new products. It can be shown that there are other combinations of policies which are more effective both in encouraging R&D and 'creating jobs' than the 'work in Canada' provision of the subsidy system.

Consider a new product Y with demand schedule DD_Y in Figure 6. The cost of producing a unit of Y in Canada is C_C. Profit maximization implies a price and output of P_C and Q_C respectively. The monopoly profit of P_CABC_C per period is the return to the resources allocated to the invention of Y.[6]

5 See Section 3.1 for details. The Gray Report (1972, 133) also recommends that 'work in Canada' restrictions attached to present programs be maintained.

6 The model employed here is generalized in McGee (1966). In McGee's version, which is illustrated below, the demand function for new product Y is DD, the production cost per unit of Y is CC and marginal licencing cost, the additional cost incurred by the Y patentee for an additional unit of Y produced under licence, is given by LL. In his simplest case, CC is the long-run supply function of an industry which is to produce Y competitively.

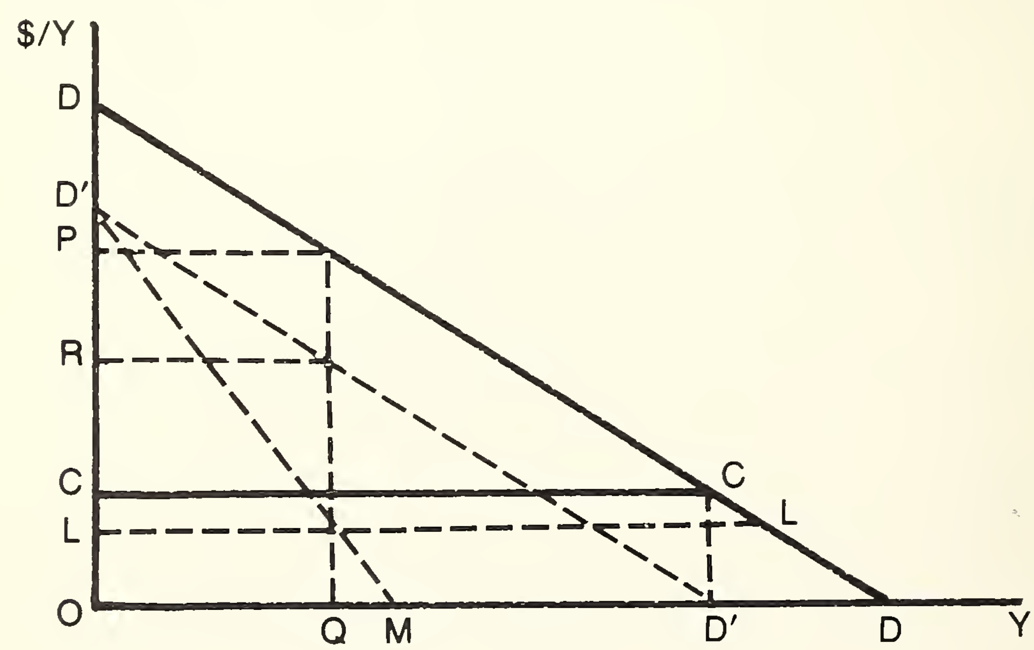
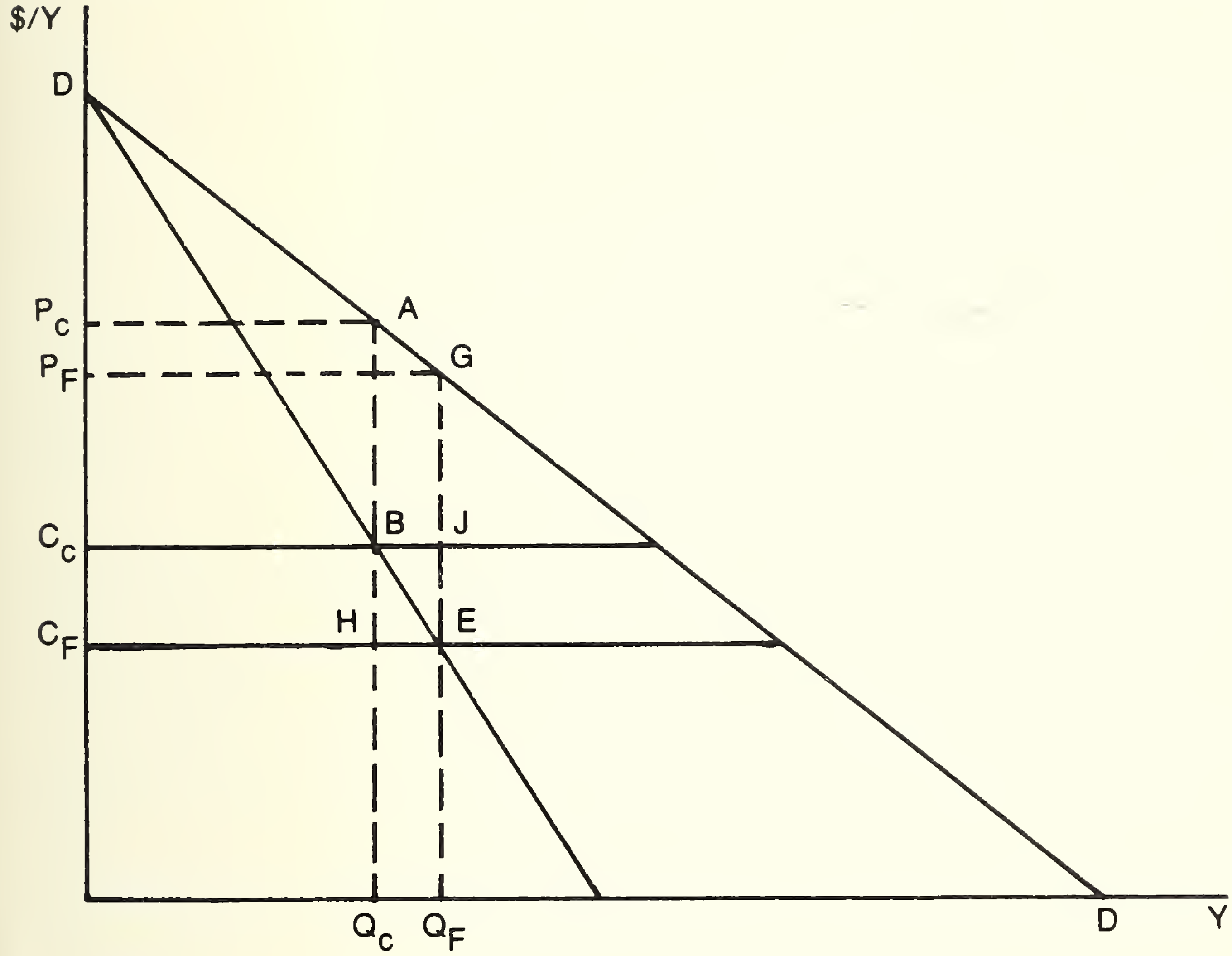


Figure 6



If C_C is lower than the cost of producing a unit of Y elsewhere in the world, Y will be produced in Canada. In this case the 'work in Canada' provision of the R&D subsidy is irrelevant.

The maximum uniform per unit royalty which can be extracted from potential licencees as a group is the difference between the demand price and the cost of production. The derived demand for licences is then the demand price less production cost of $D'\,D'$. The patentee's marginal licence revenue will be given by $D'\,M$.

The returns to the patentee will be maximized at a Y output such that marginal royalty revenue is equal to marginal licensing cost or OQ units of Y. This implies per unit royalties of OR and a Y price of OP.

For a zero marginal licensing cost, the price and output of Y, the income of the inventor of Y, and thus the implicit royalty rate are identical, obtained in the model employed in the text and illustrated in Figure 6. As McGee shows, the existence of different cost functions for different potential Y producers, non-constant returns to scale, and bilateral monopoly will influence the relative returns to the patentee for licensing as opposed to producing Y itself as well as the patentee's optimal royalty rate. Unchanged is the inventor's fundamental interest in the minimization of the production costs of the new product. For this reason the conclusions reached in this section are also valid for the range of cases considered by McGee.

If the 'work in Canada' provision is binding, the foreign production cost of a unit of Y, C_F, must be lower than the Canadian production cost. That is, without this restriction, good Y would be produced abroad. Thus, to the extent that it is effective, the 'work in Canada' provision forces the owner of the rights to Y to produce it in Canada at a higher cost.

In this case the owner of the rights to Y loses profits of C_cBEC_F per period. This is a reduction in the return to the resources allocated to the invention of Y. If the return of P_FGEC_F per period was just sufficient to induce the allocation of resources to the invention of Y, the return after the imposition of the 'work in Canada' provision, P_cABC_c per period will be insufficient. An additional subsidy equal to the lost economic of profit of C_cBEC_F per period is required if resources are to be allocated to the invention of Y.[7]

The imposition of a binding 'work in Canada' provision also reduces consumers' surplus obtained from the consumption of Y by P_cAGP_F per period. The reduction in the social return to the resources allocated to the invention of Y is the sum of this reduction in consumers' surplus and the reduction in economic profit of $P_cAGP_F + C_cBEC_F$ per period. With greater production costs and a consequent higher price, the benefits to society from inventing Y must naturally be less.

In general, then, the 'work in Canada' provision, where effective, reduces the social return to resources allocated to R&D and increases the size of the subsidy required to induce the allocation of resources of a given value to R&D.

If the resources allocated to the production of Y would otherwise be unemployed, the production of Y in Canada would, in fact, create jobs. In the present context this implies that the social (opportunity) cost of producing a unit of Y is less than C_c, and possibly less than C_F. In the latter case reliance on a comparison between domestic and foreign private costs, C_c and C_F respectively, will lead a prospective Y producer to locate abroad when Canada is, in fact, the least cost location.

Assume that the social cost of producing a unit of Y in Canada is just equal to C_F in Figure 6 so that Canadian production is as efficient as foreign production. Consider now two methods of inducing a prospective Y producer to locate in Canada. The first is to operate directly on the location decision by subsidizing domestic Y production. In the present case a per unit subsidy of $C_c - C_F$ is sufficient to induce a Y producer to locate in Canada. Given this production subsidy, profit maximization implies an output of OQ_F per period and social

7 This subsidy cannot exceed the deviation between the social and private return which is DAP_c per period.

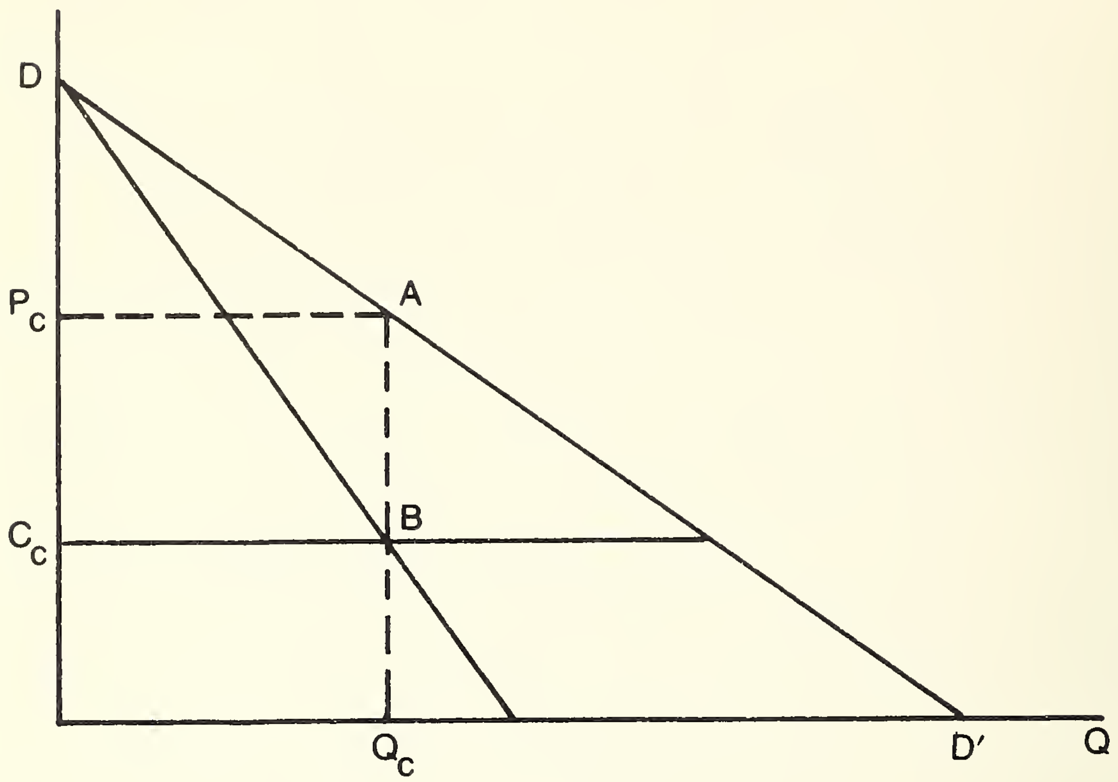
benefit net of production cost of $DGEC_F$ per period. The latter is comprised of the return to resources allocated to R&D of P_FGEC_F per period and consumers' surplus of DGP_F per period.

The alternative is to operate on the location decision indirectly by forcing recipients of R&D subsidies to produce in Canada any inventions resulting from subsidized R&D activity. No production subsidy is paid, although, as is argued above, the R&D subsidy will have to be larger. In this case a profit maximizing Y producer acting on the basis of a private per unit cost of C_c would set output at OQ_c units per period. Social benefit net of production cost is then $DAHC_F$ per period. The latter is smaller by $AGEH$ per period than the social benefit achieved using a production subsidy. This loss, both in consumers' surplus and in returns to R&D, is the result of the restriction of Y production. Y production is restricted because, while the 'work in Canada' provision achieves the goal of inducing production to locate in Canada, it does nothing to correct the excess of private over social production cost. The production subsidy does both simultaneously.

In summary, if the goal is to influence the location of production, it is always better to operate directly on the factors, relative production costs in this model, which determine location. Efforts to influence the location decision indirectly through R&D subsidies simply reduce the social benefit which flows from the R&D. Similarly, and perhaps more obviously, one would not try to influence the R&D decision by changing relative production costs.

The principle that subsidies should exert their influence on behaviour in as direct a manner as possible can be extended to cover the use of R&D subsidies to achieve various regional goals. Consider a country with two regions, M and N. Let production cost be lower in region N. Because of its relatively high production costs, region M is underdeveloped and has a relatively high unemployment rate. In an effort to reduce regional inequality the government requires that recipients of R&D subsidies produce their inventions in region M. This is exactly analogous to the 'work in Canada' provision discussed above. The 'work in region M' restriction, if it is binding, reduces the return to R&D and increases the size of the R&D subsidy required to attract resources of a given value into R&D. If, because of the high rate of unemployment in region M, the social (opportunity) cost of production is actually lower than that in region N, incentives to locate in the former are desirable. Again, the preferred alternative is to operate directly on the determinants of the locational decision subsidizing production in region M. A 'work in region M' restriction achieves the regional goal, but does so at the cost of reducing the return to R&D. The regional production subsidy entails no such cost.

Figure 7



2.4 EXPORTS AND THE RETURN TO R&D: IMPLICATIONS FOR THE ADMINISTRATION OF SUBSIDIES

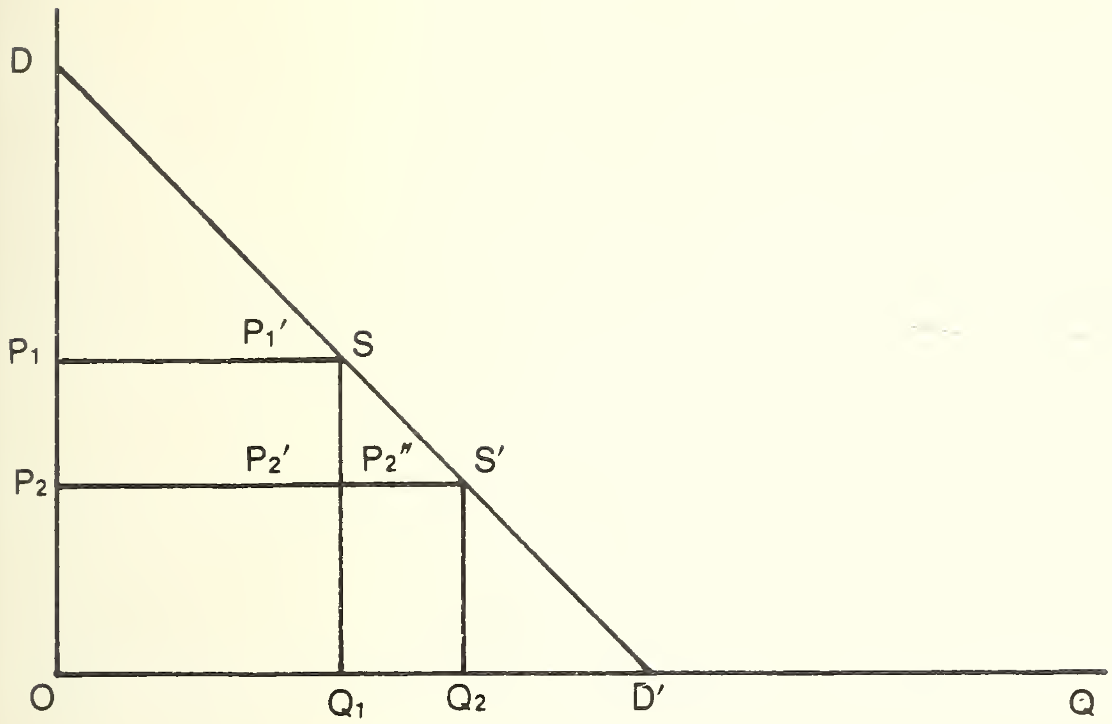
It is sometimes argued that, since exports are to be encouraged, preference should be accorded firms which produce for export when subsidies are awarded. It is contended here that a preference such as this is undesirable on economic grounds. Two illustrative cases are developed. In the first the correct policy is to make no distinction between potential domestic and export production in the awarding of R&D subsidies. In the second, the correct policy is to discriminate in favour of firms producing for the domestic market when subsidies are awarded.

Consider first product innovation Y with cost and demand conditions illustrated in Figure 7. Directed entirely to the domestic market, a profit maximizing output of OQ_c units per period generates social benefit net of production cost equal to $DABC_c$ per period. Of this P_cABC_c can be construed as the return to the resources allocated to the invention of Y. The balance, DAP_c per period, is consumers' surplus.

If the same output were exported at price P_c, the resulting foreign currency earnings would be sufficient to purchase imports valued at P_cAQ_cO in domestic funds. Consumers' surplus on these imports should, on average, amount to DAP_c per period.

In the absence of taxes and tariffs, then, the net benefit yielded by a given output of Y is the same whether this output is exported or consumed domes-

Figure 8



tically. Similarly, the return to R&D depends on the position of the demand function for Y, but not on the destination of Y production. Exports or export potential is relevant only insofar as it implies a greater demand for Y. Export sales per se are not intrinsically preferable to domestic sales. There is no reason, therefore, to discriminate between domestic and export sales when calculating the returns to an R&D project or when awarding subsidies.

An alternative model was developed in Section 1.2. A process innovation results in a downward shift of the supply function for good X. As is illustrated in Figure 8, this increases consumers' surplus by $P_1P_1'P_2''P_2$ per period. If X is consumed domestically, this is also the social return to the resources devoted to developing the process innovation. Since the private return is zero, a subsidy is both necessary and warranted. If X is exported, however, the innovation merely reduces the price paid by foreign consumers. The return to the resources allocated to R&D is zero. There is no reason to develop this innovation. Obviously, there are no grounds for an R&D subsidy.

In general, there are no grounds for the subsidization of the development of innovations which have as their principal effect the reduction in the price paid by foreigners for a Canadian good.[8] The case for subsidization becomes stronger

8 This conclusion is strictly correct only for cases in which the supply function is horizontal. See McFetridge (1976).

the greater the proportion of the output involved which is consumed domestically.[9]

It may well be the case that

> All roads lead to a link between export performance and R&D. (Gruber et al., 1967, 22)

The burden of this Section is simply that, subject to the qualifications raised above (see n. 9), the establishment of such a link has no implications for the criteria to be used in the awarding of R&D subsidies.

2.5 THE SIZE OF THE SUBSIDY

The model employed in Sections 1.2 and 2.2 to analyse the R&D decision and develop a rationale for R&D subsidies is characterized by a continuous functional relationship between social benefit and the rate of cost reduction and between the rate of cost reduction and the level of R&D expenditures. This model led to

9 There is an argument that when there are tariffs on imports, an *ad valorem* tariff at rate t, for example, export sales will generate a greater social benefit than will equivalent domestic sales. In this case, export sales will be preferable per se to domestic sales. In the context of the model of the product innovation illustrated in Figure 7, for example, the export of quantity Q_c at a price of P_c (in terms of domestic currency) allows the exporting country to purchase foreign goods valued not at P_cAQ_cO but at $(1 + t)\, P_cAQ_cO$ in domestic currency. Since $(1 + t)\, P_c$ must be a point on the demand curve for imports, consumers' surplus remains the same. The social benefit resulting from the innovations increases by tP_cAQ_cO dollars per period if the innovation is exported. If one accepts this approach, the project which results in export sales will be eligible for a greater subsidy, other things being equal, than one which does not. In the case of the model of the process innovation applied to a good which is exported, illustrated in Figure 8, a tariff on imports will result in a positive return to the innovation, provided the foreigner's elasticity of demand for the good involved exceeds one. The greater the tariff and the foreigner's elasticity of demand, the greater is the social benefit generated by the application of the process innovation to an exported good relative to that generated by its application to a good consumed domestically.

The argument that exports generate greater social benefits than equivalent domestic sales has a number of flaws. It assumes that there is no equivalent deviation between the value placed on the new invention by domestic consumers and the price received by its producer. If, for example, there is an excise tax at rate $\tau\ (=t)$ imposed on goods intended for domestic consumption, there is, again, nothing to choose between domestic and export production. Second best considerations notwithstanding, the general equilibrium implications of this argument are also unclear. What are the consequences, in aggregate, of the pursuit of a general policy of subsidizing activities which lead to exports?

the conclusion, illustrated in Figure 4, that the optimal marginal subsidy, ψ, would be such that

$$g' - G' = \psi \leqslant B' - G', \qquad (1)$$

where ψ = present value of the subsidy payment in terms of dollars per unit (percentage point) of cost reduction.

g' = present value of the R&D cost of an additional unit of cost reduction (marginal R&D cost).

G' = present value of the additional income which results from an additional unit of cost reduction (expression (10) Section 1.2) and accrues to the inventor.

B' = present value of the additional social benefit which results from an additional unit of cost reduction (expression (9), Section 1.2).

The subsidization rule obtained from this model is applicable to a wider range of cases. It may be applied, for example, to a discrete set of R&D projects, the results of which may be either product or process innovations. To illustrate the generality of the subsidization rule summarized in expression (1) the symbols employed therein may be defined on a per project basis so that

ψ = present value of the subsidy to be awarded a given R&D project,

g' = present value of the cost of the project,

G' = present value of the income net of all but project costs (g') which accrues to those undertaking the project and is attributable to the project,

G' = gross private benefit,

B' = present value of social benefit net of all but project costs and attributable to the project,

B' = gross social benefit,

$G' - g'$ = net private benefit,

$B' - g'$ = net social benefit,

$B' - G'$ = external benefit.

When applied to an individual R&D project, the subsidization rule implies, first, that any project for which gross social benefit exceeds gross private benefit

($B' - G' > 0$) should be eligible for subsidization. Because of the limited term of the patent, the prohibition of price discrimination or the complete absence of property rights, most R&D projects will be included in this category. Subsidy administrators can satisfy themselves as to the existence of an external benefit by requiring subsidy applicants to list the potential users, other than the applicant, of the results of the project and to explain why these potential users will be able to escape paying for the results they use.

The second implication of the subsidization rule is that the subsidy paid should be confined to the difference between the present value of project costs and the gross private benefit ($g' - G' = \psi$). This insures that the resources allocated to the project are receiving their opportunity cost and no more. A subsidy in excess of this amounts to a rent to those undertaking the project. It was shown in Section 2.2 that, if the latter are foreign nationals, the net social benefit resulting from the project is reduced by the amount of the 'excess subsidy.' While this is not the case when those undertaking the project are domestic nationals, those administering the subsidies may wish to avoid what is, after all, a transfer from taxpayers to inventors which does not influence the inventive activity of the latter.

The third implication of the subsidization rule is that the subsidy should never exceed the difference between gross social benefit and gross private benefit. A subsidy in excess of this difference would have the effect of inducing an overallocation of resources to R&D. The present value of the consequent reduction in national income is in this case, $g' - B'$.

In order to assure themselves that they are not paying an 'excess subsidy,' administrators should require that subsidy applicants provide estimates of both the costs of the project and the income stream, net of all but project costs, which the latter is expected to generate. Since the subsidy is confined to the difference between the present value of the costs of the project and the present value of the income stream it generates (gross private benefit), a project that earns the opportunity cost of the resources allocated to it ($G' = g'$) will receive no subsidy. Ruled out, then, is the use of the subsidy system to support projects which will be profitable for their proponents but for which financing can not be obtained. Under rule (1) the subsidy system can not be used to plug the so-called 'gaps in the capital market.'

The confinement of the subsidy to the difference between project cost and gross private benefit up to a maximum of the difference between gross social and gross private benefit provides an incentive for applicants to understate the gross private benefit and, simultaneously, to overstate the gross social benefit of any given project. It is the unenviable task of the administrator to assess the value of the results of a project to firms other than the applicant and the extent to which

the latter can obtain these results without paying. If the answer to either of these questions is 'nil,' there are no grounds for subsidization.

Another point of contention between the applicant and the administrator will be the discount rate to be applied in present value calculations. The essence of the conclusion reached in Section 1.3 is that, unless it can be demonstrated that the transactions and moral hazard cost of achieving a given amount of risk reduction through government are less than those of achieving it through the market, R&D costs and the income and social benefit streams associated with a given project proposal should be discounted at the rate at which the market normally discounts the future earnings of the applicant or other firms in a similar risk class. This discount rate could be inferred, for example, from the applicant's price : earnings ratio or from the price : earnings ratio of firms operating in a similar environment. It should not, in any case, be equal to the so-called risk free discount rate.

Division of (1) by g' yields

$$(g' - G')/g' = \psi/g' \leqslant (B' - G')/g', \tag{2}$$

which implies that, for values of G' approaching zero, the required subsidy approaches one hundred per cent of R&D costs, provided, of course, that the social benefit : cost ratio (B'/g') is equal to or greater than one. It is the current practice to confine subsidies to approximately fifty per cent of R&D costs. Under this system no project for which gross private benefit is less than half of R&D costs $(G' < .5g')$ will be undertaken regardless of its social benefit : cost ratio. The present system, therefore, discriminates against projects where the largest portion of benefits accrue to firms other than those undertaking the projects. This is precisely where a subsidy is most important. The proposed system would be free of this defect.

The requirements implicit in the subsidy rule summarized by (1) and (2) have the effect of ensuring that: (a) only projects with non-negative net social benefits $(g' \leqslant B')$ will receive subsidies; (b) the subsidized firm will never receive more than the difference between gross private benefit and the opportunity cost of the resources allocated to the relevant project $(\psi = g' - G')$; (c) the subsidy will never exceed the difference between gross social and private benefit which is the external benefit attributable to the project $(\psi \leqslant B' - G')$.

To ensure that the subsidy system has these properties, subsidy administrators will require applicants to submit: (a) estimates of project costs; (b) estimates of the income stream net of all but project costs which is generated by the project; (c) estimates of the value of project results to others; and (d) estimates of the extent to which others can be made to pay for these results.

The above subsidization rules are reassuringly similar to those advocated by Kuch (1974). In his summarization of the criteria upon which to base the general subsidization decision Kuch argues that

With respect to a particular subsidy, once it has been determined that the good involved is socially desirable (net social benefit exceeds zero) and that society receives external benefits that are at least as large as the grant ... , it is worthwhile to determine if the grant requested is larger than should be required to induce production of the good. Essentially this involves seeing how the grant alters the entrepreneur's income relative to the rest of society.

Where P represents the entrepreneur's potential profits from producing the good without the grant, let P_n be the profits he would earn from his best alternative investment involving the same outlay. Then if $P_n - P = G$ [the grant] the entrepreneur's relative income position is not changed by the grant. His inputs are earning just what they would receive in alternative uses. (12)

Although they clearly misunderstood the mechanics of its application, the members of the Senate Committee on Science Policy appeared to favour an evaluative approach similar to the above. They concluded that

The administrators of the [subsidy] program should develop their own criteria and priorities for the selection of R&D projects to be supported and the degree of assistance they should receive. They should first require private firms to present their own benefit : cost ratio and evaluation of the success potential of the innovation. The administrators should also develop techniques for measuring the social benefit : cost ratio and evaluating the chance of success. These measures will never be exact and completely reliable but they can be used as rough guidelines. In principle, when the private benefit-cost ratio is greater than one and the social ratio is lower than one, R&D projects should receive a low priority for public support. The higher the private ratio and the lower the social ratio the less public assistance is needed or justified for a given project. Cases where the social ratio is higher than the private ratio should get priority. (573-4)

While they err in the details of their analysis (no project for which the social benefit-cost ratio is less than one or less than the private benefit-cost ratio should ever receive a subsidy), the senators appear to concur, at least in part, with the principles of evaluation set out in this study.

2.6 ADMINISTRATION OF R&D SUBSIDIES: SOME GENERAL GUIDELINES

The foregoing discussion has provided both a rationale and some criteria for the administration of R&D subsidies. These can be summarized as follows:

1 Within the present legal environment the subsidization of R&D expenditures can be justified on the grounds that they result in an increase in allocative efficiency.

2 There are no discernible grounds for the use of subsidies or any other type of state intervention to bear risk.

3 The subsidy awarded any R&D project should be confined to the difference between R&D costs and the gross private benefit up to a maximum of the difference between gross social and private benefit.

4 The social rate of return to resources allocated to R&D does, under some circumstances, depend on the ownership of these resources. In simple terms, when resources are paid more than their opportunity cost, their ownership matters. If the subsidy to an R&D project is just sufficient to cover the excess of R&D costs over the present value of the private net benefit flow, the social return to the project is the same regardless of the ownership of the resources involved in it and discrimination between foreign and domestically owned subsidy applicants is unwarranted.

Since a subsidy to a foreign owned firm in excess of the difference between R&D costs and the present value of the private net benefit flow reduces the social return to R&D, while a similar error in favour of a domestically owned firm does not, the subsidy requests of the former should be scrutinized more thoroughly.

5 The effect of placing restrictions on the disposition of the results of subsidized R&D projects, if any, is to reduce the social rate of return to the resources allocated to these projects and to increase the size of the subsidy necessary to induce firms to undertake them.

The primary goal of R&D subsidies is to encourage R&D. The use of these subsidies to achieve other goals reduces their effectiveness in achieving the primary goal. This is the effect of any stipulation that the results of subsidized R&D projects be exploited in Canada or in a specific region or province of Canada. The goal of increasing employment in the manufacturing of new products can be achieved more effectively by direct subsidization of such employment.

Similar conclusions can be reached regarding the use of R&D subsidies to encourage rural life or small business or the use of certain languages. It is always more efficient to subsidize these activities directly.

6 In the absence of taxes and tariffs, export sales potential should enter into the calculation of the return to a given R&D project only insofar as it implies a larger market for any new products or processes developed. Exports per se are not intrinsically preferable to domestic sales. There are, in fact, cases in which subsidies to export oriented applicants should be avoided. As a general rule, however, no distinction should be made between export and domestically oriented applicants.

3
Evaluation of the existing subsidy system

3.1 DESCRIPTION OF THE CURRENT SUBSIDY SYSTEM

Federal tax legislation provides for two general subsidies to scientific research and development. These subsidies have the effect of raising the private rate of return to all types of scientific R&D.

The first general subsidy is implicit in Section 72 of the Income Tax Act. Since 1961 firms have been allowed to write off all R&D expenditures, other than those on physical capital used in R&D, in the year they are incurred. Since R&D expenditures are likely to exert effects which last beyond the year in which they are incurred, the proper accounting procedure is to treat R&D as intangible capital. The present system, therefore, provides an accelerated (100%) write-off for investments in 'R&D capital.' The size of the subsidy involved increases as the economic decay rate of R&D capital decreases. The size of the subsidy implied will also increase with the rate at which future profits are discounted.

The second general subsidy is provided under the Industrial Research and Development Incentives Act of 1967 (IRDIA). The IRDIA subsidy takes the form of tax free cash grants (tax credits) equal to 25 per cent of the increase in current R&D expenditures over the average of the preceding five years. It also provides for grants equal to 25 per cent of expenditures on physical capital to be used in R&D. All activities defined as R&D in the Income Tax Act and which are deemed to be of benefit to Canada are eligible for the IRDIA subsidy.[1] R&D

1 For a definition of activities acceptable for tax purposes as R&D see The Canada Gazette (1969, 1373–4).

activities are deemed to be of benefit to Canada if they are carried on for the purpose of 'strengthening the business' of the applicant and if the applicant is free to exploit any results of its R&D in Canada. The Act does not appear to disqualify applicants who are not free to exploit the results of their R&D in export markets.

The federal government also maintains four specific subsidy programs, each of which is intended to raise the private rate of return to a specific type of R&D. These programs are: the Industrial Research Assistance Program (IRAP), the Defence Industrial Research Program (DIR), the Program for the Advancement of Industrial Technology (PAIT), and the Defence Industrial Productivity Program (DIP).

IRAP was introduced in 1962 with the object of encouraging the allocation of additional resources to applied research in science or engineering in the non-defence industries. All companies which are incorporated in Canada and have the capability of exploiting the results of their research in Canada are eligible for IRAP grants. The latter take the form of the payment of salaries of scientists, engineers, and technicians added to the applicant's research staff to undertake an approved project. The subsidy cannot, in general, exceed half the cost of the project. The maximum period over which a project may receive assistance is five years.

PAIT was introduced in 1966 to provide forgivable loans to finance product or process development in the non-defence industries. The program was modified in 1969 and now provides subsidies to product and process development projects in the non-defence industries. PAIT assistance takes the form of a grant of as much as 50 per cent of current expenses plus overhead assignable to an approved development or product introduction project. All companies incorporated in Canada are eligible for subsidization under PAIT. Recipients are required, however, to exploit the results of their R&D in domestic and foreign markets from a manufacturing base in Canada 'to the extent that it is not uneconomic to do so.' Results of subsidized projects cannot be transferred abroad for purposes of manufacture without the consent of the federal government.

DIR was established in 1961 to encourage the allocation of additional resources to applied research in the defence industry.[2] DIR assistance takes the form of a grant of as much as 50 per cent of the direct costs involved in an approved project. All companies incorporated in Canada and conducting research of potential military significance are eligible for DIR assistance. Recipients

2 Defence industries include the aerospace, electrical, electronic, shipbuilding industries as well as parts of the motor vehicles industry.

must conduct their research in Canada and undertake to exploit any results in Canada.

DIP was introduced in 1959 for the purpose of encouraging the allocation of resources to product and process development in the defence industries. The DIP program also provides for the subsidization of both certain product introduction activities and the purchase of production machinery. The latter segment of the DIP program was known formerly as the 'Industry Modernization for Defence Export' (IMDE) program. A DIP subsidy generally takes the form of a grant of as much as 50 per cent of the direct cost plus the overhead assignable to approved projects.

The specific subsidy programs have several common characteristics. They are not automatic. They must be applied for and approved by the government. The assistance provided generally amounts to one-half the cost assignable to the project. All firms incorporated in Canada are eligible for assistance. Specifically, eligibility is not restricted to Canadian owned firms. There appears to be some restriction on selling R&D itself abroad. All four programs have at least a formal requirement that the results of R&D projects be worked in Canada. The implications of such a restriction were discussed in Section 2.2.

The dollar value of federal R&D subsidies awarded under the above programs is given in Table 2. The relative importance of federal subsidies as a source of funds for industrial R&D is shown in Table 3. On average the federal government appears to be the direct source of fifteen per cent of the resources allocated to industrial R&D. To the extent that resources supplied by the firm are part of the matching contribution required under the subsidy programs described above, the federal influence on R&D expenditures will be larger. The extent to which federal subsidies do, in fact, elicit a matching contribution of resources from recipients is investigated in Section 3.3. For the present it can be concluded that the federal expenditures on either subsidies or R&D contracts could be the source of as much as thirty per cent of industrial R&D spending.

3.2 CHARACTERISTICS OF SUBSIDY RECIPIENTS

In previous sections of this study we suggested a number of criteria which should be used in the administration of R&D subsidies. In this section we attempt to infer the criteria actually employed in the administration of the present subsidy system. To do this we examine the characteristics of firms receiving R&D subsidies and compare them with the characteristics of firms which do R&D but have not received subsidies. From the special characteristics of subsidy recipients one can make inferences regarding the type of firm or activity implicitly being supported by the program.

TABLE 2

Federal R&D subsidies 1967-74 ($000)

	PAIT	DIP	DIR	IRAP	IRDIA
1967	4,596	22,626	4,702	4,198	–
1968	6,364	22,904	4,499	5,086	2,131
1969	4,303	29,588	4,286	6,100	19,592
1970	5,290	48,500	4,208	6,295	23,000
1971	13,055	45,187	4,499	6,856	30,114
1972	27,428	48,500	4,500	8,430	31,278
1973	26,537	48,325	4,213	10,534	31,963
1974	25,558	57,503	4,499	11,936	30,416

SOURCE: Canada, Public Accounts (annual).

TABLE 3

Sources of funds for intramural R&D*

	Percentage					
Source	1963	1965	1967	1969	1971	1973
Reporting company	76	69	77	75	71	68
Related companies, domestic	2	2	2	4	5	1
Federal government	16	18	14	14	16	16
Industrial contracts, domestic	1	1	1	2	1	1
Other, domestic	1	1	1	1	1	1
Related companies, foreign	2	4	3	2	3	5
Industrial Contracts, foreign	1	1	1	1	1	1
Other foreign	1	4	1	1	2	2
Total	100	100	100	100	100	100

SOURCE: Statistics Canada (annual).
* Includes R&D contracts, excludes IRDIA subsidies.

The task, then, is to find the determinants of the probability of a firm's applying for and being granted an R&D subsidy. Among the possible determinants are:

a Ownership: while there is no reason to believe that foreign and domestically owned firms will differ in their propensity to apply for subsidies, there may be discrimination either for or against domestically owned firms in the awarding of

subsidies. Our theoretical analysis leads us to recommend that there be no such discrimination.

b Firm size: large firms may be more aware of and, therefore, more likely to apply for subsidies. The application process may also be sufficiently costly to discourage small applicants. On the other hand the subsidies may have been used to support small firms. The program could then display a bias in either direction. There is no reason to discriminate among applicants on the basis of size, although, in the presence of substantial transactions costs, the return to a process innovation will increase with the size of the firm introducing it.

c Size of the R&D operation: firms maintaining large R&D operations may, again, be more aware of and thus more inclined to apply for subsidization. Subsidies may have been used to support small R&D operations or to encourage the establishment of new ones. The net effect of the program may either support or discourage small R&D operations. Our theoretical analysis suggests that it is the nature of the project (deviation between its social and private rate of return) rather than the R&D operation which should be the determining factor in the subsidization decision.

d Location: there may be interregional differences in the propensity of firms to apply for subsidies. This may be either offset or reinforced by the use of the subsidy system to effect interregional transfers by discriminating in favour of firms in a favoured region. Our analysis leads us to the advocacy of a strict separation of the objectives of encouraging R&D and diminishing regional inequalities. Locational subsidies or direct interregional transfers should be used to attack the latter problem.

e Financial condition: failing firms may be more inclined to apply for subsidization. If the government wishes to avoid their failure they may also be more likely to have their applications approved. This would, of course, be inimical to the objective of encouraging productive R&D efforts.

f Nature of the product: the subsidy system may reflect a particular 'industrial strategy.' That is, subsidies may have been used to encourage the development of either new products of a particular nature (SIC category) or new processeses with a particular application. This intention may be offset or reinforced by inter-industry differences in the propensity of firms to apply for subsidies. The analysis presented here implies that subsidies may be concentrated in a few industries if the set of projects for which the excess of social over private returns is similarly concentrated. There are, however, no other grounds for such a concentration of subsidies.

The relationship suggested by the above discussion may be summarized symbolically as

$$P(G_{it}) = f(O_i, S_{it-1}\ R_{it-1}, H_i, P_{it-1}, Q_{it-1}, I_i) \tag{1}$$

where

$P(G_{it})$	=	probability of the ith firm receiving an R&D subsidy during period t,
O_i	=	dummy variable to indicate the nationality of ownership of the ith firm,
S_{it-1}	=	sales of the ith firm during the previous period,
R_{it-1}	=	R&D expenditures of the ith firm during the previous period,
H_i	=	dummy variable to indicate the region in which the ith firm is headquartered,
P_{it-1}	=	profits of the ith firm during period t,
Q_{it-1}	=	quick ratio (current assets/current liabilities) of the ith firm at the end of the previous period,
I_i	=	dummy variable to indicate the SIC industry to which the ith firm is assigned.

If we let f_j, $j = 1 \ldots 7$ be the derivative of the function with respect to the ith argument, a finding that f_2 exceeds zero would imply that the probability of obtaining an incentive grant increases with the size of the firm. That is, the system discriminates in favour of larger firms. Similarly, a finding that both f_5 and f_6 are negative indicates that the worse the financial health of a firm, the greater is its chance of obtaining an R&D grant.

If the dummy variable O_i equals one if the ith firm is foreign and zero otherwise, then a finding that f_1 exceeds zero implies that foreign owned firms have a higher probability of receiving subsidies. In this case there is implicit discrimination in favour of foreign owned firms.

If the classical linear regression model were to be employed in the estimation of (1), the population regression model would be written as

$$P(G_{it}) = X\beta + \mu_{it}, \tag{2}$$

where $i = 1 \ldots N$, $t = 1 \ldots T$, X is an NT X k matrix of the observations on k independent variables defined in (1), β is a k X 1 vector of regression coefficients and μ_{it} is an NT X 1 vector of random disturbances. $P(G_{it})$ will be an NT X 1 vector of zeros (when no grant is received) and ones (when a grant is received). $P(G_{it})$ does not, therefore, have the properties assumed of it in the classical linear regression model. In particular, it is not normally distributed. While this is not

necessarily fatal, Goldberger (1964) has shown that estimates of this model will have heteroskedastic residuals which have the effect of biasing, in an indeterminant direction, the usual tests of significance. In addition, there will exist values of the independent variables such that $P(G_{it})$ will be outside the required zero to one range.

A solution to this problem is to transform $P(G_{it})$ into a variable y such that $y = X\beta$ and $-\infty < y < \infty$. This can be done via either a probit or a logit transformation. In a probit transformation one assumes that for given values of the independent variables (which can be represented by the $1 \times k$ vector X^*) the probability of receiving a subsidy is given by the value of the cumulative standard normal density function at $X^*\beta$. Thus

$$P(G_{it}) = F(y) = F(X^*\beta) = (2\pi)^{-\frac{1}{2}} \int_{-\infty}^{X^*\beta} e^{-z^2/2}\, dz, \tag{3}$$

so that the transformed variable y is defined implicitly as

$$y = F^{-1} P(G_{it}) \tag{4}$$

and $-\infty < y < \infty$ as required. By (3), each of the $P(G_{it})$ is a function of the β so that maximum likelihood estimators of the β can be found by maximizing the logarithm of the likelihood function of the sample with respect to β. If there are V cases in which subsidies are awarded and therefore $NT - V$ cases in which they are not awarded, the logarithm of the likelihood function of the sample is

$$\ln L = \sum_{j=1}^{V} \ln P(G_j) + \sum_{j=V+1}^{NT} \ln(1 - P(G_j)). \tag{5}$$

The maximization procedure is described in Cragg (1968).

The logit transformation results in the creation of a variable y such that

$$y = \ln\left[P(G_{it}) / (1 - P(G_{it}))\right] = X\beta. \tag{6}$$

y is merely the logarithm of the odds in favour of obtaining a subsidy. As required, $-\infty < y < \infty$ for $O \leqslant P(G_{it}) \leqslant 1$. In this case the β can be estimated by the maximum likelihood method as described by Cragg (1968) or by least squares as suggested by Theil (1971).

Both the probit and logit models are applied to the data set described in the Appendix. Estimates of the probability of receiving a subsidy given various combinations of ownership, size, financial condition, location, and industry are reported for the probit model in Table 4 and for the logit model in Table 5.

TABLE 4

Probability of applying for and receiving a subsidy: probit function

Industry	Loss in previous year	Head-quarters	Sales	R&D Budget in previous year	Ownership	Year	Current assets ÷ current liabilities	$P(G)$
Communications (SIC 335)	no	Ontario	$25 million	$1 million	Domestic	1971	2.13*	.63
Communications (SIC 335)	no	Ontario	$25 million	$1 million	Foreign	1971	2.13*	.81
Communications (SIC 335)	no	Quebec	$25 million	$1 million	Foreign	1971	2.13*	.92
Communications (SIC 335)	no	Quebec	$25 million	$1 million	Domestic	1971	2.13*	.79
Communications (SIC 335)	no	Ontario	$50 million	$1 million	Foreign	1971	2.13*	.89
Communications (SIC 335)	no	Ontario	$50 million	$1 million	Domestic	1971	2.13*	.74
Industrial chemicals (SIC 378)	no	Ontario	$25 million	$1 million	Domestic	1971	2.13*	.03
Industrial chemicals (SIC 378)	no	Ontario	$25 million	$1 million	Foreign	1971	2.13*	.08
Industrial chemicals (SIC 378)	no	Quebec	$25 million	$1 million	Foreign	1971	2.13*	.19
Industrial chemicals (SIC 378)	no	Quebec	$25 million	$1 million	Domestic	1971	2.13*	.08
Industrial chemicals (SIC 378)	no	Ontario	$50 million	$1 million	Domestic	1971	2.13*	.05
Industrial chemicals (SIC 378)	no	Ontario	$50 million	$1 million	Foreign	1971	2.13*	.15

* Sample mean.

TABLE 5

Probability of applying for and receiving a subsidy: logit function

Industry	Loss in previous year	Head-quarters	Sales	R&D Budget in previous year	Ownership	Year	Current assets ÷ current liabilities	$P(G)$
Communications (SIC 335)	no	Ontario	$25 million	$1 million	Domestic	1971	2.13*	.62
Communications (SIC 335)	no	Ontario	$25 million	$1 million	Foreign	1971	2.13*	.81
Communications (SIC 335)	no	Quebec	$25 million	$1 million	Foreign	1971	2.13*	.93
Communications (SIC 335)	no	Quebec	$25 million	$1 million	Domestic	1971	2.13*	.82
Communications (SIC 335)	no	Ontario	$50 million	$1 million	Foreign	1971	2.13*	.86
Communications (SIC 335)	no	Ontario	$50 million	$1 million	Domestic	1971	2.13*	.70
Industrial chemicals (SIC 378)	no	Ontario	$25 million	$1 million	Domestic	1971	2.13*	.03
Industrial chemicals (SIC 378)	no	Ontario	$25 million	$1 million	Foreign	1971	2.13*	.08
Industrial chemicals (SIC 378)	no	Quebec	$25 million	$1 million	Foreign	1971	2.13*	.20
Industrial chemicals (SIC 378)	no	Quebec	$25 million	$1 million	Domestic	1971	2.13*	.08
Industrial chemicals (SIC 378)	no	Ontario	$50 million	$1 million	Domestic	1971	2.13*	.04
Industrial chemicals (SIC 378)	no	Ontario	$50 million	$1 million	Foreign	1971	2.13*	.11

* Sample mean.

The results obtained from these alternative estimation methods are virtually identical. Among the conclusions which can be drawn from these results and which reference to either Table 4 or Table 5 will confirm are that, all else being equal, the probability of receiving a subsidy: (a) did not differ from year to year over the sample period; (b) was greater for foreign than for domestically owned firms; (c) was not affected by the size of the previous year's R&D budget; (d) increased with firm size but at a decreasing rate so that it reached a maximum for firms with annual sales of 280 million dollars in 1971; (e) was greater for firms with headquarters in Quebec than for firms whose headquarters were elsewhere in Canada.

The effect of the financial condition of the firm on the probability of its receiving a subsidy is ambiguous. Firms with lower quick ratios did have a greater probability of receiving a subsidy. Firms which earned losses during the previous year had a lower probability of receiving a subsidy. These two results are not necessarily contradictory. A firm can be short of working capital but still not be making losses, and vice versa. It was also found that a longer history of losses (two previous years or three previous years) did not affect the probability of receiving a subsidy. If one accepts this last result, one is left with the conclusion that a relatively weak cash position, as reflected in a low quick ratio, increased the probability of a firm's receiving assistance, but that a relatively weak economic position, as reflected in losses over a number of past periods, did not affect that probability.

The probability of receiving a subsidy differs substantially from industry to industry. The industries involved can be dichotomized into higher and lower probability groups. The industries in the former include electrical equipment and appliances, paint and varnish, and plastic fabrication. Those included in the latter are non-electrical machinery and chemicals. There is no indication from these results that there is any type of industrial activity which has been favoured implicitly by the subsidy system.

One must be cautious in interpreting and employing these results. As can be seen from the results provided in Tables 4 and 5 fully two-thirds of the difference in the probability of receiving a subsidy is due to the industry in which the firm operates. This is most likely the result of inter-industry differences in research opportunities and is not of particular interest for policy purposes. Moreover, the probability measured here is that of applying for and receiving a subsidy. A bias against one type of firm or activity may be offset by a greater propensity to apply for assistance. This may be the reason that the financial variables do not exert an unambiguous influence on the probability of receiving assistance. Other conclusions must be similarly qualified. One can conclude, for example, only that firms with headquarters in Quebec were either more likely

than firms with headquarters elsewhere either to apply for assistance or to have applications accepted or both. The same caveat applied to conclusions drawn regarding large firms and foreign owned firms.

3.3 RESPONSES OF RECIPIENTS TO SUBSIDIZATION[3]

As was indicated in Section 3.1 the R&D subsidies offered by the federal government take the form of a cost sharing arrangement whereby the government normally pays one-half the cost of the R&D projects it chooses to support. Payments are made only upon proof of equivalent expenditures by the firm. Insofar as individual projects are concerned, expenditures by the firm from its own funds match public funds dollar for dollar. When we consider the entire R&D budget of the firm, however, no such compulsion exists. The receipt of an incentive grant may increase, decrease, or leave unchanged the total R&D expenditures of the recipient. If the subsidy is awarded in support of a project which the recipient would not otherwise have undertaken (an extra-marginal project) and the latter does not abandon other unsubsidized projects which it would otherwise have undertaken, its R&D expenditures will increase by the amount of the subsidy. The subsidy has the effect of increasing the value of resources devoted to R&D by both the public and private sectors.

At the other extreme is the case in which the subsidy is awarded in support of a project which the recipient would have undertaken in any case (an intra-marginal project). The recipient is able to reduce the value of its own resources devoted to R&D by the amount of the subsidy. In this case the subsidy system does not affect the value of resources allocated to R&D. It merely results in the replacement of private with public funds.

The R&D expenditures of subsidy recipients may not change at all. This will occur if the subsidy is awarded to an extra-marginal project and the recipient transfers resources from other projects to pay for its share, or if the subsidy is awarded in support of an intra-marginal project and the recipient transfers the resources saved to other R&D projects. In this case the effect of the subsidy is to increase the value of resources devoted to R&D by the amount of the subsidy and no more. The private sector does not increase the value of resources it devotes to R&D. The increase is due entirely to the public sector and, in expenditure terms, is the same as would be achieved by development contract or additional 'in-house' R&D expenditures.

3 The findings reported in this section are taken from J.D. Howe and D.G. McFetridge, "The Determinants of R&D Expenditures," (1976).

Finally, if the returns to alternative R&D projects are interdependent, the receipt of a subsidy in support of one project may raise returns to others. The effect of this could be to increase R&D expenditures by more than the amount of the subsidy.

It is evident that the success of the present system in increasing the value of resources allocated to scientific research and development is crucially dependent on the responses of subsidy recipients. The latter can, by cutting their own R&D budgets, completely nullify the effect of the subsidies. On the other hand, if firms react by increasing their budgets, the effect of the subsidies is reinforced.

The nature of the response to subsidization can be determined by specifying and estimating a multiple regression model which predicts the R&D expenditures of a firm with a given set of characteristics and comparing this with the R&D expenditures of a firm with similar characteristics but which is also a recipient of an R&D subsidy. If it is observed that the latter is spending more on R&D, this is taken as evidence that the subsidy has induced its recipient to make R&D expenditures greater than those it would ordinarily make.

The R&D expenditures which a firm would ordinarily make will be an increasing function of its size (in terms of sales) and of its internal cash flow (profits after taxes plus depreciation). This is illustrated by the following simple model of the R&D decision.

Consider a firm facing the demand schedule

$$P = A - BQ, \tag{1}$$

where P is price per unit and Q is quantity demanded. Long-run marginal cost is constant at C_1 dollars per unit of output. A process innovation shifts the cost function downward to C_2, as illustrated in Figure 9. The innovation has the effect of increasing the profits of the firm by C_1FGC_2 dollars per period.

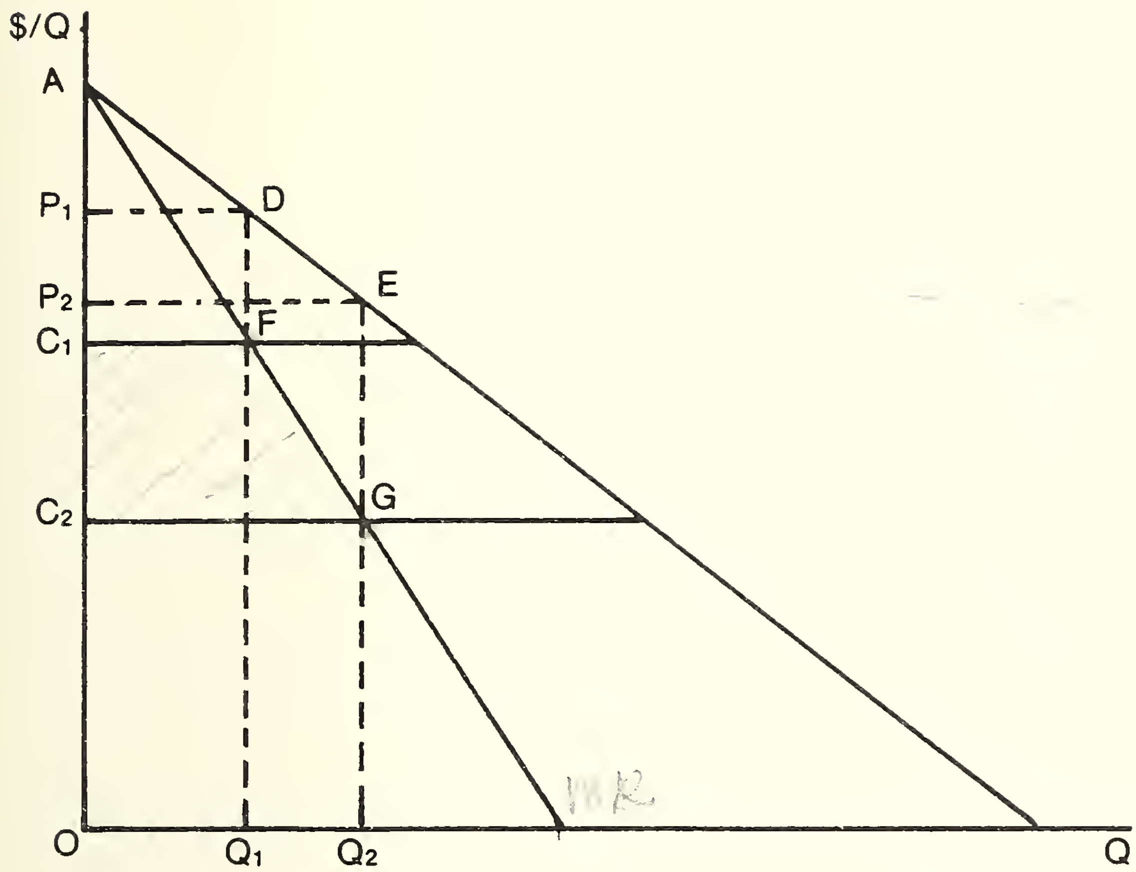
Provided that A exceeds one, C_1 can be set equal to one so that the change in marginal cost due to the innovation, ΔC, is also its rate of change, $\dot{C}$. The present value of the increase in profits resulting from the innovation can then by expressed as a function of the initial level of output, Q_1, the slope of the demand function, B, and the discount rate, r. Thus,

$$\Delta\pi = [CQ_1 + (1/4B)\dot{C}^2]/r, \tag{2}$$

The effect of a change in the rate of cost reduction on the present value of the increase in profits is given by the marginal profit function

$$(d/d\dot{C})\ (\Delta\pi) = [Q_1 + (1/2B)\dot{C}]/r = \Delta\pi'. \tag{3}$$

Figure 9



Assume now that the marginal R&D cost (in present value terms) of a change in the rate of cost reduction is an increasing linear function of the rate of cost reduction. Thus

$$(d/d\dot{C})\ (R) = k\dot{C} = R', \tag{4}$$

where R is the present value of the R&D expenditure required to achieve a given percentage reduction in production cost.

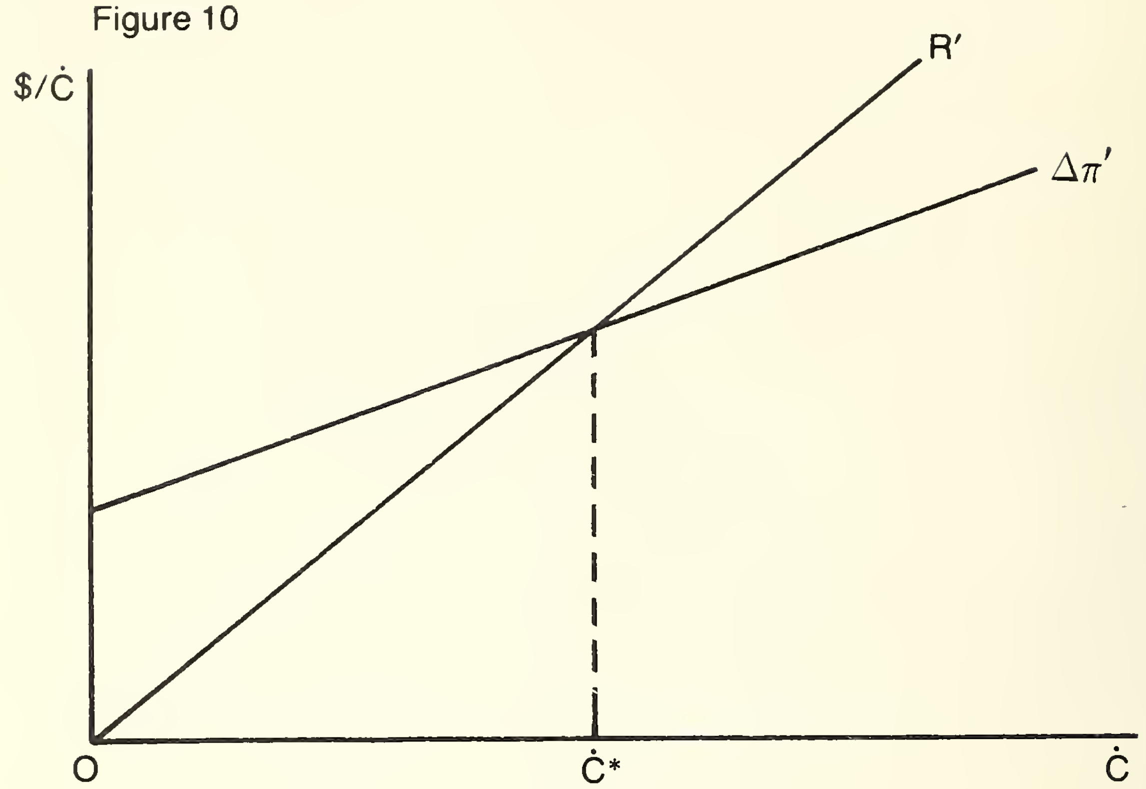
Functions (3) and (4) are shown in Figure 10. Profit maximization requires a rate of cost reduction, $\dot{C}^*$, such that marginal R&D cost equals the marginal change in the present value of profits. The equilibrium rate of cost reduction is then

$$\dot{C}^* = [Q_1 + (1/2B)\dot{C}]/kr, \tag{5}$$

which is stable provided k exceeds $2Br$. The present value of the R&D expenditures required to achieve a percentage cost reduction of $\dot{C}^*$ is

$$R^* = \int_0^{\dot{C}^*} k\dot{C}\ d\dot{C} = [Q_1 + (1/2B)\dot{C}]^2/kr^2. \tag{6}$$

Figure 10



The profit maximizing level of R&D expenditures is thus an increasing function of the initial level of output, $(\partial R^* / \partial Q_1 > 0)$ and a decreasing function of the discount rate $(\partial R^* / \partial r < 0)$. Because there are no transactions costs involved in raising funds within the firm, there are grounds for accepting a lower rate of return on them than would be acceptable in the case of external sources of finance. In this case, other things being equal, the discount rate will decrease as internal cash flow increases.

The precise nature of the effect of a change in firm size on the profit maximizing level of R&D depends on the shape of the marginal R&D cost function (Howe & McFetridge, 1976; Kamien & Schwartz, 1975). To allow for the variety of shapes that function might assume, the R&D-firm size relationship is specified as a cubic. The relationship between R&D expenditures and both after-tax profits and depreciation is assumed, for the sake of simplicity, to be linear.

The foregoing leads to the following regression model

$$R_{it} = a_0 + a_1 S_{it} + a_2 S_{it}^2 + a_3 S_{it}^3 + a_4 P_{it} + a_5 A_{it} + a_6 G_{it} + \epsilon_{it}, \tag{7}$$

where

R_{it} = R&D expenditures from its own funds of the ith firm during year t,

S_{it} = sales of ith firm during year t,

P_{it} = profits after tax but before deduction of R&D expenditures of the ith firm during year t,

A_{it} = depreciation charges of the ith firm during year t,

G_{it} = government R&D incentive grants received by the ith firm during year t,

ϵ_{it} = a random disturbance.

If the estimate of a_6 is such that $O > \hat{a}_6 > -1$, one can infer that recipients of subsidies reduce their own R&D spending below its normal level. If $\hat{a} > 0$, the subsidies increase the value of resources allocated by the private sector to R&D. If $\hat{a} = 0$, recipients of subsidies do not change R&D spending and the effect of the subsidy system is no different from that of a development contract or of 'in-house' R&D expenditures by the government.

If either the implications of the simple R&D decision model described in equations (1) ... (6) or the U.S. pattern are any guidance, R&D expenditures will increase with sales initially at an increasing rate and ultimately at a decreasing rate ($\hat{a}_1, \hat{a}_2 > 0, \hat{a}_3 < 0$) and with after-tax profits and depreciation changes ($\hat{a}_4, \hat{a}_5 > 0$) (Kamien & Schwartz, 1975). Finally, for reasons discussed in Howe and McFetridge (1976), the effect of firm size and cash flow on R&D, hence the a_j, will differ from industry to industry and between foreign and domestically owned firms.

The data used to estimate this model are described in the Appendix. Estimation problems are discussed in detail in Howe and McFetridge. Estimates of the model are reported in Table 6. As expected the $\hat{a}_j$ differ from industry to industry (a different set is reported for each of the electrical, chemical, and machinery industries) and between ownership classes. Of principal relevance here, however, are the $\hat{a}_6$ which are summarized in Table 7.

In the case of both the machinery and chemical industries, at conventional significance levels, one cannot reject the null hypothesis that a_6 is zero,[4] that is, recipients of subsidies do not change their overall R&D budgets. The value of resources allocated by society to R&D rise by the amount of the subsidy and no more. Insofar as R&D spending is concerned, the government could have achieved the same result by awarding a development contract or by conducting the R&D itself.

In the electrical industry both foreign and domestically owned firms which received subsidies spent more on R&D than they would ordinarily have spent. Domestically owned firms increased their spending by more than the amount of

4 In the chemical industry, the critical t-value is 1.984, while the actual t value is 1.97. a_6 is, therefore, different from zero at the 5.1% significance level.

TABLE 6

Equation (1) by industry

1 Electrical industry

$$
\begin{aligned}
R = {} & \underset{(4.98)}{108.63\ D1} + \underset{(4.70)}{301.92\ D2} + \underset{(4.37)}{.019\ D1S} - \underset{(2.82)}{.017\ D2S} \\
& - \underset{(2.26)}{.108(10^{-6})\ D1S^2} + \underset{(4.18)}{.277(10^{-6})\ D2S^2} + \underset{(3.07)}{.313(10^{-12})\ D1S^3} \\
& - \underset{(3.21)}{.343(10^{-12})\ D2S^3} - \underset{(1.16)}{.082A} - \underset{(.43)}{.017\ D1P} + \underset{(5.01)}{.429\ D2P} \\
& + \underset{(2.77)}{.538\ D1G} + \underset{(9.03)}{1.31\ D2G}
\end{aligned}
$$

$\bar{R}^2 = .78 \qquad N = 104 \qquad F(12, 91) = 31.3$

2 Chemical industry

$$
\begin{aligned}
R = {} & \underset{(3.45)}{90.88} + \underset{(.45)}{.0018S} + \underset{(1.35)}{.089(10^{-6})\ D1S^2} + \underset{(10.66)}{1.27(10^{-6})\ D2S^2} \\
& - \underset{(.58)}{.146(10^{-12})\ D1S^3} - \underset{(11.06)}{7.65(10^{-12})\ D2S^3} - \underset{(.65)}{.015A} + \underset{(.41)}{.009\ D1P} \\
& + \underset{(3.31)}{.104\ D2P} + \underset{(1.97)}{.862\ G}
\end{aligned}
$$

$\bar{R}^2 = .76 \qquad N = 103 \qquad F(9, 93) = 37.7$

3 Machinery industry

$$
\begin{aligned}
R = {} & \underset{(5.10)}{139.51} + \underset{(.84)}{.004S} + \underset{(.22)}{.018(10^{-6})S^2} - \underset{(.23)}{.062(10^{-12})S^3} + \underset{(2.47)}{.249A} \\
& - \underset{(1.22)}{.062P} + \underset{(.88)}{.51G}
\end{aligned}
$$

$\bar{R}^2 = .29 \qquad N = 49 \qquad F(6, 42) = 4.28$

NOTE: Variables as defined in text. $D1 = 1$ if ith firm foreign owned, zero otherwise. $D2 = 1 - D1$. t-ratios in brackets.

the subsidy they received. This implies that the subsidies had the effect of making other, non-subsidized projects profitable. Foreign owned firms increased spending but by less than the amount of the subsidy they received. This implies that at least some resources were transferred from other projects to meet the requirements of subsidized projects. In both cases, however, the value of resources allocated by society to R&D increases by more than the amount of the subsidy. The private sector has been induced to increase its R&D spending. Neither a development contract nor in-house government R&D can achieve this result.

TABLE 7

Response to subsidies

Type of firm	$\hat{a}_6$
Electrical, domestically owned	1.31*
Electrical, foreign owned	.54*
Chemical	.86**
Machinery	.51

* Denotes significantly different from zero at 1% level.
** Denotes significantly different from zero at 10% level.

The subsidy system has not resulted in a simple replacement of private by publicly controlled resources in the R&D field. On the other hand its success in inducing the private sector to increase its commitment to R&D has been limited to the electrical products industries. Even this limited success may have more to do with both the defence orientation and the thoroughgoing public participation in both the R&D projects and their subsequent exploitation, which is prevalent in this industrial sector. This is a matter for further study.

3.4 RATES OF RETURN TO R&D

The previous two sections contained an investigation of the characteristics of subsidy recipients and of the extent to which the latter are induced by the subsidy to increase their own R&D expenditures. This section contains an examination of the methods by which both social and private rates of return to R&D can be calculated and an assessment of the limited evidence available on rates of return to R&D in Canada.

In this study a prominent role has been assigned to the rate of return to R&D. In Section 1.2, it is assumed that private rates of return provide the signals which guide the allocation of resources within the firm. In Chapter 2, it is advocated that social rates of return be used to guide governmental resource allocation decisions in general and subsidization decisions in particular. One is, therefore, obliged both to indicate how such rates of return might be calculated and to provide some evidence on the return to resources devoted to R&D in Canada. If the latter is not at least as great as that which can be earned in alternative applications, there is no need to encourage R&D.

There are a number of methods by which the ex ante rate of return to R&D may be calculated. They can be calculated on a project basis and adjusted to a

social rate of return using familiar benefit : cost techniques. The literature on the application of the techniques of project evaluation to the choice of R&D projects is surveyed by Clarke (1974). The effectiveness of these techniques in this particular application is investigated by Mansfield and Brandenburg (1966) and Mansfield et al. (1971). This literature indicates that, although there are many difficulties, ex ante rates of return to R&D can serve as a basis for discriminating among alternative uses of the resources of a firm. The concept of the profit maximizing level of R&D, of which extensive use was made in earlier chapters, has an operational foundation. It is more than a 'convenient fiction.'

If the debate regarding the amount of resources which it is in this country's interest to devote to R&D is to be resolved, some information on ex post social rates of return to R&D is required. Some information of a qualitative nature is provided in a recent study by Charles and Mackay (1975). The latter examine the R&D programs of eighteen firms operating in Ontario and are able to identify sixty technical innovations resulting from these programs. Of these, twenty-nine were described by the companies involved as having been 'profitable.' Since thirteen of the companies examined received R&D subsidies under either the PAIT or the IRAP program, we cannot infer that innovations which were profitable to the firm involved necessarily earned the requisite social rate of return. Similarly, the thirty-one innovations judged 'unprofitable' by the firms involved may have earned the requisite social rate of return or have had the potential of doing so. In this case the subsidies involved may have been insufficient.

Charles and Mackay (1975, 55) also report that, of the eighteen R&D operations examined, twelve resulted in innovations 'which had very marked effects on the fortunes of the companies involved in terms of sales, profits and jobs'. Increases in 'sales' and 'jobs' do not, of course, indicate that resources allocated to R&D have earned their opportunity cost. Such an inference would be warranted if the present value of the incremental profits resulting from these innovations exceeded the opportunity cost of the resources required to make them. A closer examination of the profit effects of the innovations cited in this study is clearly desirable.

Mansfield (1965) has attempted to estimate the rate of return to R&D expenditures at the firm level without a detailed case study of each R&D project. On the assumption that R&D generates factor augmenting technical change and that the production function is Cobb-Douglas, Mansfield is able to estimate rates of return to R&D for five U.S. chemical firms and five U.S. petroleum firms. Depending on the rate at which new knowledge is assumed to decay, Mansfield obtains estimates of the rate of return to R&D between one and seventeen per cent for the five chemical firms and between eleven and ninety-six per cent for the five petroleum firms. Although this model is applicable only to firms conducting

research into possible process (as opposed to product) innovations and employs a highly simplistic model of production, it is a good example of the types of insights which can be gained by employing limited (and public) information.

Other investigators have responded to the absence of case studies upon which to base estimates of rates of return to R&D at the firm or project level by estimating average rates of return using cross-sections of firm level data (Mansfield, 1965; Branch, 1974; Minasian, 1969), geographic cross-sections (Griliches, 1964) and industry cross-sections (Mansfield, 1968; Lithwick, 1969; Globerman, 1972).

Both the Lithwick and the Globerman studies sought to explain interindustry differences in the rate of growth of total factor productivity by interindustry differences in R&D expenditures. Both authors assumed, in effect, a Cobb-Douglas technology such that

$$Q = AK^{\alpha}L^{\beta}R^{\gamma} \tag{1}$$

and

$$\frac{dQ}{Q} = \alpha\frac{dK}{K} + \beta\frac{dL}{L} + \gamma\frac{dR}{R}, \tag{2}$$

$$\frac{dQ}{Q} - \alpha\frac{dK}{K} - \beta\frac{dL}{L} = \gamma\frac{dR}{R}, \tag{3}$$

where Q = value added output of the ith industry during year t,

K = capital stock of the ith industry during year t,

L = labour force of the ith industry during year t,

R = stock of R&D capital of the ith industry during year t.

Lithwick used exogenous estimates of α and β to calculate the left-hand side of (3), which is defined as the rate of growth of total factor productivity or $d\left\{Q/(\alpha K + \beta L)\right\} / \left\{Q/(\alpha K + \beta L)\right\}$ for each industry. He then calculated the coefficient of rank correlation between these values and industry R&D expenditure : sales ratios. He could not reject the null hypothesis that the coefficient of rank correlation was zero.

Globerman chose to estimate (2) directly and infer the marginal product of R&D (capital) from his estimate of γ. Instead of dR/R, the rate of change in the stock of knowledge (R&D capital), he used the industry R&D expenditure : sales ratio. With the model so specified Globerman found that he could reject the null hypothesis that γ equals zero in favour of the alternative that γ is negative. His

estimate of the marginal product of and thus the rate of return to R&D is negative (Globerman, 1972, 186)[5]

These studies serve principally to illustrate the problems that will be encountered by anyone attempting to measure cross-sectional average rates of return to R&D. The model employed by these investigators will not reflect the effect of R&D which results in product rather than process innovations. Even if attention is confined to process innovations, the effect of R&D in industry i may be to increase factor productivity in industry j. As a result, positive social rates of return to R&D are quite compatible with estimates of γ which do not differ significantly from zero.

Neither of these investigators is able to employ an appropriate measure of the stock of R&D capital. Deflating annual R&D expenditures by sales is clearly inappropriate. To obtain a measure of the stock of R&D capital one must take into account both current and past R&D expenditures and make an assumption about their decay rate. Neither current nor annual average R&D expenditures have this effect.

Given their operational and conceptual limitations, these models would, at best, provide only weak evidence regarding the rate of return to R&D. The fact remains, however, that economists have yet to produce any statistical evidence that the rate of return to industrial R&D in Canada is not zero. The absence of such evidence is all the more bothersome in the light of the high positive rates of return inferred by U.S. investigators from similar models.

Minasian (1969), for example, has applied a model similar to (1) to a cross-section of seventeen U.S. chemical firms observed over the period 1948–57. He estimated the gross rate of return to R&D at 54 per cent.[6] Griliches (1964), also using a model similar to (1), found that the gross rate of return to the research and extension expenditures of a cross-section of state agricultural experiment stations observed during the years 1949, 1954, and 1959 was of the order of 300 per cent.

Other investigators have stopped short of estimating the rate of return to R&D but have, nevertheless, found a relationship between R&D expenditures and some

5 Results obtained after this by dropping the rate of change of the capital stock (192) are meaningless.

6 The net rate of return after allowing for depreciation of the stock of knowledge is obtained by deducting the assumed decay rate, δ, from 54 per cent. The net rate of return is negative for $\delta >$ .54. A reader of the Minasian study should be aware that Minasian can not have obtained the estimates he reports by the method he describes. The use of '... a general constant and seventeen specific constants – one for each firm ...' (81) when the cross-section is composed of seventeen firms will cause the matrix of the independent variables to be singular.

measure of inventive output. Comanor (1965) found a positive relationship between the R&D expenditures and the subsequent new drug sales of U.S. pharmaceuticals firms. Scherer (1965) found a positive relationship between the R&D expenditures and the subsequent patenting activity of 448 of the 500 largest U.S. industrial companies. Mansfield (1968) found a positive relationship between U.S. expenditures and the number of innovations subsequently carried out among firms in the American steel, chemical, and petroleum industries.

Each of these investigators was able to infer the existence of an input-output relationship for scientific research. Their studies did not support inferences regarding ex post rates of return to R&D. Their approach is adopted, of necessity, in this study. It proved possible to infer, within a Canadian context, a relationship between R&D expenditures and subsequent patenting activity. A discussion of the model employed in this endeavour appears below. Attempts to estimate ex post rates of return were plagued by estimation problems arising principally from the limited information provided by the sample and were abandoned.[7]

The establishment of a relationship between R&D expenditures and a measure of inventive output is, it must be admitted, only a beginning. It supports the inference that the allocation of resources to R&D has some measurable effect, that it will result in an increase in the stock of inventions. More specifically, it would allow the rejection of the allegation that the R&D expenditures reported by firms operating in Canada are, at best, for product testing and quality control and are not intended to result in new products or processes. It does not support a test of the hypothesis that the resources allocated to R&D were wasted.

The number of patents obtained per year is employed in this study as an index of the inventive output of the firm. As a number of investigators have observed, the number of patents obtained by a firm is a highly imperfect measure of its inventive output (see Comanor & Scherer, 1969; Mueller, 1966). Since some innovations may be either ineligible for patent protection or kept secret, the number of inventions produced by a firm may exceed the number of patents it obtains. Alternatively, one invention may be surrounded by a number of 'defensive' patents and a firm's patenting activity overstates the number of inventions actually produced. If the number of patents obtained is to reflect the number of inventions produced (or innovations made), one must recognize and remove both interindustry and interfirm differences in the propensity to patent. Scherer (1965) eliminates the influence of interindustry differences in the propensity to patent, in effect, by analysing patenting activity on an industry basis.

7 A description of the model employed in the attempt to estimate *ex post* rates of return can be found in an earlier version of this study and is also available from the author.

He then assumes that remaining interfirm differences in the propensity to patent are random. The same procedure is adopted in this investigation.

Elimination of the effect of differences in the propensity to patent yields an index which reflects interfirm differences in the volume, not the value, of inventive output. Although there are conditions under which the value (net social benefit) of inventive output is proportional to the number of patents obtained, the likelihood that these conditions will prevail is low and any inferences made would be highly qualified.[8] Inferences made here are, therefore, confined to those regarding the existence of a relationship between R&D and the volume of innovative activity.

A simple relationship between the value of past R&D inputs and inventive output could be written as

$$P_{it} = k_0 + k_1 \Sigma w_k R_{it-j-k} + \epsilon_{it}, \qquad (4)$$

where

P_{it} = patents obtained by the ith firm during period t,

R_{it-j-k} = R&D expenditures of the ith firm during year $t - j - k$,

and

$$\sum_{\text{all } k} w_k = 1.$$

Current patenting activity is a function of past R&D activity. It is not, however, a homogeneous function. It seems reasonable to include a constant term in

8 Scherer (1965) suggests that, if the present value of the net benefit associated with a given patent is a random variable, B, with expectation $E(B) = B^*$, and one regresses patents, P, on R&D expenditures, R, so that the population regression model is

$$E(P) = f(R).$$

then, given the property of the sample regression line that $\hat{P}|R = E(P|R)$, the expected net benefit associated with a given level of R&D spending is

$$E(B \cdot P|R) = E(B)\, E(P|R) = B^*\hat{P}.$$

The social net benefit is proportional to the number of patents obtained. This result obtains only if the net benefit per patent, B, and the number of patents obtained, P, are independent. There is no reason to believe that this will be the case. Moreover, as Scherer notes (1098), there is evidence that random variable B is distributed according to the Pareto distribution. In this case a finite B^* does not exist.

the model and thus allow for a situation in which inventions occur and patents are obtained without any formal R&D effort.

If the propensity to patent varies from industry to industry, both k_0 and k_1 in equation (4) will vary from industry to industry. The practice of allowing all the coefficients in the model to differ from industry to industry is equivalent to estimating the model for each industry under investigation. For this reason equation (4) and its variants are estimated for each of the two digit SIC. industries under investigation. These are, as before, the electrical, chemical, and machinery industries.

From a random sample of patents granted during the period under investigation it was determined that, on average, three years elapsed between the date on which an application for a patent is filed and the date on which it is granted. Thus, a patent obtained during period t is the result of R&D done during or before period $t - 3$. The lag distribution on R&D should therefore begin at period $t - 3$ ($j = 3$ in equation (4)).

A large proportion of the patents obtained by firms operating in Canada are the result of the secondment to those firms of the Canadian rights to discoveries made by foreign affiliates. Since there is no reason for the number of such patents to bear a functional relationship to the R&D expenditures of the firms under investigation, they are excluded from the analysis. The dependent variable in equation (4), P_{it}, is, therefore, the number of patents for which there is either a Canadian resident inventor listed or, if the inventor resides abroad, Canada is the first nation in which patent protection has been sought, granted annually to the ith firm.

The process which generates the variation, both among firms and over time, in the number of patents obtained is likely to be more complex than that implied by equation (4). If R&D personnel are viewed as working with a stock of knowledge that is fixed over a given period of time (a year in this case), the law of variable proportions will apply to the relationship between R&D expenditures and patents obtained. The marginal product of R&D will be an increasing function of R&D expenditures for low values of the latter and a decreasing function of R&D expenditures for higher values of the latter. This implies that (4) be modified to allow for a non-linear relationship between R&D expenditures and patents obtained.

A second modification of (4) will be required if the number of patents resulting from a given level of R&D expenditures increases or decreases with the size of the firm within which the R&D is conducted. If larger firms are characterized by a greater degree of separation of those doing R&D from those making decisions regarding its application, the cost of transmitting information regarding research needs down to the researchers and the cost of tramsmitting information

regarding research capabilities up to decision-makers will be higher.[9] The cost of forcing researchers to pursue the goals of the firm rather than their own will also be greater. The effect of this is, in the simplest terms, that decision-makers will use proportionately less of the output of their researchers, researchers will pursue proportionately fewer of management's objectives and more of their own, and a given level of R&D spending results in fewer inventions which are patentable by the firm.[10] In this case, firm size (as reflected by its sales, S) should appear as an independent variable with a negative coefficient in equation (4).

If, on the other hand, the larger firm conducts a wider range of activities (is more diversified), the cost to it of discovering a profitable application of the results of any given R&D project may be lower. The diversified firm may also have a higher probability of finding a profitable internal use for the results of a given R&D project. Given the transactions costs associated with the sale to other firms of the rights to a new invention, the profitability of a new invention may increase with the degree to which it can be used internally. In this case the profitability and thus the incentive to continue a project until it results in patentable inventions may be greater, the larger the firm. Firm size as reflected by sales should then appear as an independent variable with a positive coefficient in equation (4).

A change in firm size may affect either or both of the marginal and the average product of R&D. If it affects only the average product of R&D

$$\left[\left.\frac{\partial P}{\partial S}\right|_R \neq 0\right],$$

the number of patents resulting from a given level of R&D spending will change with firm size. This phenomenon will be of interest to persons, such as anti-combines authorities, wishing to know whether the merger of two firms would enable them to make better use of a given R&D outlay. If firm size acts on the marginal product of R&D

$$\left[\frac{\partial^2 P}{\partial R \partial S} \neq 0\right],$$

9 See Williamson (1967) for a discussion of the limits to the size of a hierarchical organization.

10 It may result in more inventions patentable by individual researchers or a flow of research people, accompanied by their inventions, to other firms.

the change in the number of patents resulting from a given change in R&D expenditures will itself depend on the size of the firm involved. This will be of interest to those such as administrators of R&D subsidies wishing to know the class of firms in which an R&D subsidy of a given value will result in the greatest increase in inventive output.[11] The modification of equation (4) must be such as to allow for the effect of firm size on both the average and marginal product of R&D. This can be done by entering firm size both additively and multiplicatively with R&D expenditures on the right-hand side of (4).

For any given level of R&D expenditures and any given firm size, inventive output may differ between foreign and domestically owned firms. The inventive output which a foreign owned firm obtains from a given level of R&D expenditures will exceed that of a domestically owned firm if the former can acquire access at nominal cost to the technical expertise of foreign affiliates. On the other hand, it has been alleged that the R&D operations of foreign owned firms are principally engaged in product testing and in cataloguing the technical developments which occur elsewhere. The type of research which would produce patentable inventions is left to the parent. In this case the inventive output yielded by a given level of R&D expenditures will be smaller for a foreign owned firm than for a domestically owned firm.

Incorporation of the modifications suggested above into equation (4) yields

$$P_{it} = K_0 + k_1 R^*_{it} + k_3 (R^*_{it})^2 + k_3 S^*_{it} + k_4 (S^*_{it})(R^*_{it}) + k_5 F_i + u_{it}, \tag{5}$$

where

$$R^*_{it} = \sum_{\text{all } k} w_k R_{it-j-k},$$

$$S^*_{it} = \sum_{\text{all } l} a_l S_{it-j-l},$$

F_i = one if the ith firm is foreign owned, zero otherwise,

S_{it} = sales of the ith firm during year t.

The marginal product of R&D is

11 This assumes that the response to subsidization, a_6 in equation (7), Section 3.4, is the same across size classes.

$$\frac{\partial P_{it}}{\partial R^*_{it}} = k_1 + 2k_2 R^*_{it} + k_4 S^*_{it}. \tag{6}$$

It increases (decreases) with R&D expenditures if k_2 exceeds (is less than) zero. It increases (decreases) as firm size increases if k_4 exceeds (is less than) zero.

The average product of R&D is

$$\frac{P_{it}}{R^*_{it}} = \frac{k_0}{R^*_{it}} + k_1 + k_2 R_{it} + \frac{k_3 S^*_{it}}{R^*_{it}} + k_4 S^*_{it} + k_5 \frac{F_i}{R^*_{it}}. \tag{7}$$

It increases (decreases) as firm size increases if the expression $(k_3/R^*_{it}) + k_4$ exceeds (is less than) zero. It is higher (lower) for foreign owned firms if k_5 exceeds (is less than) zero. It is an increasing (decreasing) function of the value of R&D expenditures if the expression $k_2 - [(k_0 + k_5 - k_3 S_{it}^*)/R^*_{it})^2]$ exceeds (is less than) zero.

Equation (5) is estimated for each of the electrical, chemical, and machinery industries (major groups), using a sample of eighty-one firms observed over the years 1967–71. The characteristics of the sample are described in the Appendix.[12]

As was indicated earlier in this section, the practice of estimating the model for each major group allows for interindustry differences in both the average and marginal propensity to patent. The intercept term, k_0, is also allowed to vary both from year to year and across three digit SIC industries. Since all other coefficients are constrained to be the same from year to year and for each three digit industry within a major group, this is equivalent to allowing for variation in the average but not in the marginal propensity to patent over time and over three digit industries within each major group. Any remaining differences in the propensity to patent are assumed to be random.

On occasion, the term S_{it}^* in equation (5) is either replaced by or used in conjunction with $(S_{it}^*)^2$ in order to allow for a non-linear relationship between inventive output and firm size.

The lag distributions upon which R_{it}^* and S_{it}^* are based were chosen so as to minimize the standard error of estimate of the equation in which they appeared. The lag distributions chosen are:

$$R_{it}^* = .6R_{it-3} + .4R_{it-4},$$
$$S_{it}^* = .33S_{it-3} + .33S_{it-4} + .33S_{it-5}.$$

12 The number of patents obtained by each of the sample firms during the period 1970–74 were taken from the *Patent Office Record,* volumes 98-102.

TABLE 8

Estimates of equation (11)

Industry	Independent variables								
	R^*	$(R^*)^2$	S^*	$(S^*)^2$	$(R^*)(S^*)$	F	$\bar{R}^2$	N	F
Electrical	$.19(10^{-2})$	–	$-.21(10^{-4})$	$.24(10^{-9})$	$-.49(10^{-8})$	-1.58	.90	149	219.8
	(6.27)	–	(2.17)	(8.68)	(6.33)	(2.79)			
Chemical	$.89(10^{-3})$	–	$-.18(10^{-4})$	–	$.15(10^{-7})$	.22	.77	123	82.6
	(2.86)		(2.85)		(5.18)	(.52)			
Machinery	$.56(10^{-2})$	–	$.77(10^{-4})$	–	$-.47(10^{-7})$	.56	.37	72	9.3
	(3.62)		(3.36)		(3.56)	(.70)			

TABLE 9

Marginal product of R&D expenditures

1 Electrical

$$\frac{\partial P}{\partial R} = .19(10^{-2}) - .49(10^{-8})S^*$$

2 Chemical

$$\frac{\partial P}{\partial R} = .89(10^{-3}) + .146(10^{-7})S^*$$

3 Machinery

$$\frac{\partial P}{\partial R} = .56(10^{-2}) - .47(10^{-7})S^*$$

SOURCE: Table 8.

Estimates of equation (5) are reported in Table 8. Estimates of the marginal product of R&D and of the effect of firm size on the average product of R&D appear in Tables 9 and 10 respectively.

Inspection of Tables 8 and 10 reveals that, other things being equal, an increase in R&D expenditures results in a subsequent increase in patenting activity in each of the three major groups investigated. In each case the effect of a given increase in R&D spending on subsequent patenting activity depends on the size of the firm but not on the level of R&D spending itself.[13] To be more specific, the marginal product of R&D is positive and an increasing function of firm size in the case of the chemical industry. It is initially positive and a decreasing function of firm size in the case of the electrical and machinery industries. In the former, the marginal product of R&D is zero for firms with annual sales in excess of four hundred million 1969 dollars. This does not imply that these firms have no inventive output. It implies that additions to the R&D budgets of firms in this industry and size class would not, other things being equal, result in additional patents.[14]

13 The coefficients of $(R^*_{it})^2$ never differed significantly from zero and this variable has been dropped from the equations reported. Estimates of equations including $(R^*_{it})^2$ are available from the author.

14 Although the relationship between the marginal product of R&D and firm size is statistically significant, the calculations of elasticities of patenting activity with respect to firm size reveal that it is not important quantitatively. In the electrical industry, for example,

TABLE 10

Effect of firm size on the average product of R&D

1 Electrical

$$\frac{\partial}{\partial S}\frac{P}{R} = .48(10^{-5})\frac{S^*}{R^*} - \frac{.21}{R^*} - .49(10^{-4})$$

2 Chemical

$$\frac{\partial}{\partial S}\frac{P}{R} = \frac{-.18}{R^*} + .15(10^{-3})$$

3 Machinery

$$\frac{\partial}{\partial S}\frac{P}{R} = \frac{.77(10^{-4})}{R^*} - .47(10^{-7})$$

SOURCE: Table 8.

The R&D cost of an additional patent is simply the inverse of the marginal product of R&D. The former is therefore a decreasing function of firm size in one case, the chemical industry and an increasing function of firm size in the case of the electrical and machinery industries. For a firm with annual sales of ten million dollars the marginal cost of a patent of 541 thousand dollars, 962 thousand dollars and 182 thousand dollars in the electrical, chemical, and machinery industries respectively.

The determinants of the level of patenting activity for any given level of R&D spending, that is, the average product of R&D, can be inferred from Tables 8 and 10. In one case, that of the electrical industry, foreign owned firms obtain fewer patents for any given level of R&D spending than do domestically owned firms. In the other two industries the average product of R&D is not affected by ownership.

In no case is there an unrestricted positive relationship between firm size and the average product of R&D. In the machinery industry the positive relationship

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an increase in annual sales from one to two hundred million dollars reduces the marginal product of R&D (in patents per thousand dollars R&D) by .0005 patents or thirty-five per cent. The implied elasticity of patenting activity with respect to firm size is –.35.

In the machinery industry, a similar increase in firm size results in a decrease of .0047 patents per year per thousand dollars R&D, which is a 45 per cent increase and implies an elasticity of .45.

between firm size and the number of patents which result from a given R&D outlay holds for R&D outlays of less than \$1.67 million. For larger R&D budgets the relationship is negative. In the chemical industry, an increase in firm size increases the average product of R&D for any R&D budget in excess of 1.2 million dollars. In the electrical industry, the average product of R&D increases with firm size for all firms with annual sales in excess of 44 million (1969) dollars. These findings give rise to the conclusion that, subject to the qualifications raised above, larger firms are able to extract more in terms of patented inventions, from a given R&D outlay than are small firms.

It was reported above that the marginal product of R&D does not depend on the level of R&D spending. If patenting activity were a homogeneous function of R&D expenditures, this would also imply constant returns to scale in the R&D operation itself. Given non-zero intercept terms (not reported) and annual sales in excess of zero, however, the simple patents-R&D relationship will have a positive intercept. In this case the average product of R&D approaches the marginal product asymptotically from above. The mirror image of this is the average cost per patent (R^*/P) which will approach marginal cost asymptotically from below. More intuitively, the existence of a positive intercept implies that a firm will obtain some patents without making any R&D expenditures. When R&D expenditures are made, additional patents are obtained but the average number of patents per dollar R&D spending must fall.

These findings, while highly tentative, are nevertheless gratifying when compared with the results reported earlier in this study. A link between R&D expenditures and some measure of inventive output has been established. The greater the reported R&D expenditures, the greater the number of patents, whether useful or not, subsequently obtained. While this result is not sufficient to support the rejection of the hypothesis that resources allocated to R&D are wasted, it is a step in that direction. As such it is distinctly superior to a finding that there is a zero or negative correlation between reported R&D expenditures and subsequent patenting activity. A finding that those reporting the large R&D expenditures are not the ones making patentable inventions and vice versa would render even more tenuous the grounds for public subsidization of R&D.

From the relationship found to exist between firm size and patenting activity it can be inferred, first, that, in the case of the chemical industry, a given increase in R&D spending results in a greater number of patents, the larger is the firm within which it occurs. The reverse is true of both the electrical and machinery industries. If profits were proportional to the number of patents obtained, additional R&D expenditures would yield more in terms of additional

profits among the larger firms in the chemical industry and among the smaller firms in the electrical and machinery industries.[15] Since these classes of firms can obtain a given additional stream of benefits at a lower cost, profit maximization requires, all else being equal, that they undertake relatively more R&D. The subsidy necessary to induce firms of either class to make R&D expenditures in excess of those which maximize profit is the same.

Second, increases in firm size will increase the patenting activity associated with a given R&D budget for all sizes of firms in the chemical and machinery industries and for all firms with annual sales in excess of 44 million 1969 dollars in the electrical industry.[16] Mergers among firms in these categories could be defended on the grounds that they increase the productivity of resources devoted to R&D.

Finally, in the case of the electrical industry, a link between ownership and the productivity of R&D expenditures has been established. In this industry foreign owned firms have either a lower propensity to patent or are conducting an R&D operation which is less likely to yield patentable inventions than that of a domestically owned firm. This could reflect the confinement of subsidiary R&D activities to product testing, quality control, and cataloguing scientific developments taking place elsewhere.

The investigation of the relationship between the patenting activity and subsequent profitability of firms is a logical next step for this study. Explanatory efforts in this direction have indicated that the completion of this next step would require more resources than have been made available to conduct this study. It must therefore be left as a topic for future investigation.

3.5 THE EVALUATION OF THE EXISTING SUBSIDY SYSTEM: SOME CONCLUSIONS

This chapter has reported the results of three complementary approaches to the examination of the effectiveness of subsidies to scientific R&D carried out in industry.

15 Comanor and Scherer (1969) are able to infer the gross private benefit (new sales) generated by a patent while both Branch (1974) and Scherer (1965) can make inferences about the net private benefit generated by an additional patent. The latter found, for example, that an additional patent generated additional after-tax profits of one hundred and forty-seven thousand dollars per year.

16 Note, however, that in all cases there are restrictions on the size of the R&D budget for which these conclusions will hold.

The first approach is to determine the characteristics of subsidy recipients. If the latter have a common characteristic, a history of making losses, for example, one can infer that the subsidy system is being used to achieve a goal, the support of failing firms in this case, other than that of encouraging R&D. To the extent that it is employed to alternative ends the subsidy system is less effective in its primary role, that of encouraging scientific R&D.

The probability of receiving a subsidy is determined principally by the industry in which a firm is operating and, to a lesser extent, by the size of the firm, its ownership, and its location. These results are more likely to reflect the distribution of applicants than a bias in the subsidy system itself. To the extent that it is the latter, it is worthwhile to repeat the warning that any discrimination or restrictions based on the ownership or the location of the applicant can only reduce the return to the R&D involved and the effectiveness of the subsidy itself.

The second approach is to determine whether the subsidies have actually increased the value of the resources allocated by society to R&D. A subsidy system which does not have this effect is clearly without justification. It was found that in all cases, the subsidy system had the effect of inducing recipients to increase the value of resources devoted to R&D by at least the amount of the subsidy. To this extent the system has been effective. The extent to which recipients have increased the value of their own resources which are allocated to R&D in response to subsidization has, however, been limited. The system has not, therefore, effected the reallocation expected of it.

The third approach is to determine whether R&D expenditures have any tangible results. If they do not there is clearly no point in encouraging them. It was found that the larger a firm's reported R&D spending, the greater is the number of patents subsequently obtained. A link is, therefore, established from subsidies to R&D to patenting activity. Whether these patents are of any value to society is a question which remains unresolved. What is clear is that subsidies do increase reported R&D spending and that reported R&D spending does result in inventions of some kind being made.

4
General conclusions

This study has avoided assertions regarding the type of life and society to which Canadians should aspire. It has confined itself to policy recommendations which can be derived directly from a simple, albeit abstract, theory of the role of the state in economic life. This theory assumes that the principal criterion by which one evaluates proposed government actions is their effect on real per capita income. To the resulting accusations of myopia or 'little thinking,' one can only reply that the conclusions expressed throughout this study follow logically from the theory employed while many of the recent 'grand designs' for science policy are obscure in both origin and intent and contradictory in application.

The importance of the assumption made regarding the role of the state in the economy can be seen most clearly in Chapters 1 and 2 which deal with the rationale for state intervention and the administration of subsidy systems respectively. State intervention in the production of new knowledge has always been justified as a necessary response to the inappropriability of new knowledge (Arrow, 1962, 616-19, 623-5). It is the essential result of Section 1.2 that state intervention changes the form of, but does not eliminate, the inappropriability problem. Since it has yet to be demonstrated that the state has an inherent advantage in dealing with this problem, its intervention does not necessarily make us 'better off.' Similarly, the potential for risk reduction in an economy is technical datum. Risk reduction via diversification or risk sharing entails costs which can be avoided neither by the state nor the market. The undertaking by the state of a risk bearing function does not necessarily make us 'better off.'

Given the institutional constraints imposed by the limited nature of the property rights awarded those producing new knowledge, the subsidization of

R&D can be shown to increase per capita income. Restrictions on either the nature of, or the activities of, recipients were shown to reduce per capita income in virtually all cases.

The theory in Chapters 1 and 2 and the empirical evidence in Chapter 3 can be combined to yield guidelines for public policy towards foreign owned firms and recommendations for future research. It was concluded that, since any government subsidy in excess of the difference between the cost of R&D resources and the private return from them, is, if paid to a foreign owned firm, a resource cost rather than a transfer, it reduces the social rate of return to the subsidized project. There is a potential real income gain, therefore, from a more thorough scrutiny of the subsidy applications of foreign owned firms.[1] This is all the more important, given our finding that, although foreign owned firms generally spend less on R&D in Canada (see Section 1.4), they are more likely to apply for and receive an R&D subsidy (see Section 3.2).

There are a number of areas in which the material presented in this study could be extended productively. The first is a theoretical and institutional investigation of the nature and extent of the property rights of those producing new knowledge. The discussion in Chapter 1 has indicated that it may prove socially advantageous to extend both the range of innovations in which property rights inhere and the extent to which benefits generated may be appropriated by the innovators.

The second is a comprehensive comparison of the costs of conducting R&D within firms and within government organizations. The discussion in Chapter 1 predicted that government research operations would incur costs of a different sort than those incurred by a firm operating in a market environment. These costs are not necessarily lower than those experienced by the firm and it is very important to have some theoretical grounds upon which to allocate research tasks between 'private' and 'public' institutions.

The third is the operationalization of the subsidization criteria developed in Chapter 2. Research on the appropriate discount rate to be applied to the estimated benefit streams provided by applicants and techniques for estimating the flow of both profits and external benefits resulting from a given project is required before these criteria can be applied.

The fourth is the estimation, on either an aggregate or an individual project basis, the ex post rates of return to R&D. This would include both privately and

1 There is also a potential real income gain from abandoning the relatively rigid 50% cost sharing rule of the existing subsidy system where foreign owned firms are concerned. See Section 3.1 for details of present cost sharing arrangements.

publically conducted R&D projects. To answer this question is to answer what, to this author, is the fundamental question of whether the effect of both past and contemplated future R&D efforts is to make Canadians as a group more or less wealthy.

Appendix

The empirical work reported in Sections 1.4, 3.2, 3.3, and 3.4 was done at the Department of Industry, Trade and Commerce in Ottawa. Results are reported with the permission of the Department. With the exception of the R&D incentive grants, which are taken from the Public Accounts (annual), all variables were drawn by the Department of National Revenue from T-2 Income Tax returns and made available under conditions of strictest confidentiality to the Department of Industry, Trade and Commerce in order to assist the latter in evaluating the effectiveness of incentive programs under its jurisdiction.

Except where otherwise specified, R&D expenditures are as defined in the Canada Gazette (1969) and exclude both inventive grants, R&D done extramurally, and R&D done under contract. All other variables are defined in the text.

The sample consists of observations drawn upon a total of 107 firms coded by Statistics Canada to one of the electrical, chemical, or machinery manufacturers major groups. Observations were taken for each of the years 1967–71. The sample was drawn from among firms which had applied for a tax rebate under the IRDIA program during any one of the years 1967–71. The sample is not random in the sense that all firms chosen will have reported positive R&D spending during at least one of the years 1967–71.

After allowing for missing observations (the membership of the cross-sections differs slightly from year to year) and screening out erroneous observations (negative sales or assets, for example), sample sizes were as follows: (a) Section 1.4 model (1), 253; model (2), 234; (b) Section 3.2, 459; (c) Section 3.3,

electrical products manufacturers, 104, chemical products manufacturers, 103, machinery manufacturers, 49; (d) Section 3.4, 259.

The sample sizes are obtained, in all cases, by pooling annual cross-sections. The problems associated with the pooling of time-series and cross-section data are discussed in Howe and McFetridge (1976).

Bibliography

Arrow, K.J. (1962) 'Economic welfare and the allocation of resources for invention.' In R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity* (Princeton: Princeton University Press)

Arrow, K.J. and Robert C. Lind (1970) 'Uncertainty and the evaluation of public investments.' *American Economic Review* 60, 264-78

Branch, Ben (1974) 'Research and development activity and profitability: a distributed lag analysis.' *Journal of Political Economy* 82, 999-1011

Canada (1972) *Foreign Direct Investment in Canada* (Ottawa, Information Canada

– (1971) Science Council of Canada, Report No. 15, 'Innovation in a cold climate: the Dilemma of Canadian manufacturing' (Ottawa: Information Canada)

– (1973) *Report of the Special Senate Committee on Science Policy,* 'A Science Policy for Canada' (Ottawa: Information Canada)

– (Annual) *Patent Office Record* (Ottawa: Information Canada)

– (Annual) Public Accounts: Details of Revenues and Expenditures (Ottawa: Information Canada)

– (1969) *The Canada Gazette,* Part II, Statutory Orders and Regulations, Vol. 101, No. 17, Sept. 13

Charles, M.E. and D. Mackay (1975) 'Case studies of industrial innovation in Canada.' University Grant Program Research Report, Department of Industry, Trade and Commerce (Ottawa)

Clarke, Thomas E. (1974) *Decision Making in Technologically Based Organizations: A Literature Review of Present Practice* (Ottawa: Ministry of State for Science and Technology)

Comanor, William S. (1965) 'Research and technical change in the pharmaceutical industry. *'Review of Economics and Statistics* 47, 182-90
Comanor, William S. and F.M. Scherer (1969) 'Patent statistics as a measure of technical change.' *Journal of Political Economy* 77, 392-8
Cragg, J.G. (1968) 'Some statistical models for limited dependent variables with applications to the demand for durable goods' Discussion paper No. 8, Department of Economics, University of British Columbia
Eads, George (1974) U.S. government support for civilian technology: economic theory versus political practice.' *Research Policy* 3, 2-16
Economic Council of Canada, Fifth Annual Review, *The Challenge of Growth and Change* (Ottawa, The Queen's Printer, 1968)
Economic Council of Canada (1971) *Report on Intellectual and Industrial Property* (Ottawa: Information Canada)
Globerman, Steven (1972) 'The empirical relationship between R&D and Industrial growth in Canada.' *Applied Economics* 4, 181-95
Goldberger, Arthur S. (1964) *Econometric Theory* (New York: Wiley)
Grabowski, Henry G. (1968) 'The determinants of industrial research and development: a study of chemical, drug and petroleum industries. *'Journal of Political Economy* 76, 292-306
Grasley, Robert H. (1975) *The Availability of Risk Capital for Technological Innovation and Invention in Canada.* Ministry of State for Science and Technology (Ottawa: Information Canada)
Griliches, Zvi (1958) 'Research costs and social returns: Hybrid corn and related innovations.' *Journal of Political Economy* 66, 419-31
– (1964) 'Research expenditures, education and the aggregate agricultural production function.' *'American Economic Review* 54, 961-74
Grubel, Herbert B. and Anthony D. Scott (1966) 'The international flow of human capital.' *American Economic Review* 56, 268-74
Gruber, William, Dileep Mehta, and Raymond Vernon (1967) 'The R&D factor in international trade and the international investment of United States industries.' *Journal of Political Economy* 75, 20-37
Hettich, Walter (1975) 'Bureaucrats and public goods.' *Public Choice* 21, 15-25
Hirshleifer, Jack (1971) 'The private and social value of information and the reward to inventive activity.' *American Economic Review* 63, 561-73
Howe, J.D. and D.G. McFetridge (1976) 'The determinants of R&D expenditures.' *Canadian Journal of Economics* 9, 57-71
Jensen, Michael C. and William H. Meckling (1975) 'Theory of the firm: managerial behavior, agency costs and ownership structure.' Working paper Series No. GPB-75-3, University of Rochester, Graduate School of Management
Johnston, J. (1972) *Econometric Methods* (New York: McGraw-Hill)

Kamien, Morton I. and Nancy L. Schwartz (1975) 'Market structure and innovation: a survey.' *Journal of Economic Literature* 13, 1-37

Kindleberger, C.P., ed. *The International Corporation (Cambridge:* MIT Press)

Kmenta, Jan. (1971) *Elements of Econometrics* (New York: Macmillan)

Kuch, P.J. (1974) 'A framework for evaluating public grants to private enterprise.' (Mimeo, University of Western Ontario, London)

Lithwick, N.H. (1969) *Canada's Science Policy and the Economy* (Toronto: Methuen)

Macrakis, Michael S., ed. (1974) *Energy: Demand Conservation and Institutional Problems* (Cambridge: MIT Press)

Mansfield, Edwin (1965) 'Rates of return to industrial research and development.' *American Economic Review* 55, 310-22

– (1968) *Industrial Research and Technological Innovation: An Econometric Analysis* New York: (Norton)

Mansfield, Edwin and Richard Brandenburg (1966) 'The allocation, characteristics and outcome of the firm's research and development portfolio: a case study.' *Journal of Business* 39, 447-64

Mansfield, Edwin, John Rapoport, Jerome Schnee, Samuel Wagner and Michael Hamburger (1971) *Research and Innovation in the Modern Corporation* (New York: Norton)

McFetridge, D.G. (1976) 'The Distribution of Research Grants: A Comment and an Extension,' *Economic Record* (in press)

McGee, John S. (1966) 'Patent exploitation: some economic and legal problems.' *Journal of Law and Economics* 9, 135-62

Minasian, J.R. (1969) 'Research and dèvelopment, production functions and rates of return.' *American Economic Review* 59, 80-6

Mueller, Dennis C. (1966) 'Patents, research and development and the measurement of inventive activity.' *Journal of Industrial Economics* 15, 26-37

Nordhaus, Wilham D. (1967) *Invention, Growth and Welfare: A Theoretical Treatment of Technological Change* (Cambridge: MIT Press)

Ontario (1975) Select Committee on Economic and Cultural Nationalism, 'Final Report on Economic Nationalism,' (Toronto: The Queen's Printer for Ontario)

Parker, J.E.S. (1974) *The Economics of Innovation* (London: Longman's)

Plant, Arnold (1934) 'The economic theory concerning patents for innovations.' *Economica* 1, 30-51

Safarian, A.E. (1966) *Foreign Ownership of Canadian Industry* (Toronto: McGraw-Hill)

– (1969) *The Performance of Foreign Owned Firms in Canada* (Montreal: Private Planning Association)

Scherer, F.M. (1972) 'Nordhaus' theory of optimal patent life: a geometric reinterpretation.' *American Economic Review* 62, 422-7
- (1965) 'Corporate inventive output, profits and growth.' *Journal of Political Economy* 73, 290-7
- (1965) 'Firm size, market structure and the output of patented inventions.' *American Economic Review* 55, 1097-1123

Schmookler, Jacob and Zvi Griliches (1963) 'Inventing and maximizing.' *American Economic Review* 53, 725-9

Schmookler, Jacob (1966) *Invention and Economic Growth* (Cambridge: Harvard University Press)

Statistics Canada (annual) 'Corporation and Labour Union Returns Act: Part I.' Cat. No. 61-210 (Ottawa: Statistics Canada)
- (Annual) 'Industrial research and development expenditures in Canada 1973-1975.' Cat. No. 13-203 (Ottawa: Statistics Canada)

Stigler, G.J. (1968) *The Organization of Industry* (Homewood: Irwin)

Theil, H. (1971) *Principles of Econometrics* (New York: Wiley)

Williamson, Oliver E. (1967) 'Hierarchical control and optimum firm size.' *Journal of Political Economy* 75, 123-38
- (1975) *Markets and Hierarchies: Analysis and Antitrust Implications* (New York: The Free Press)

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8 Government Support of Scientific Research and Development: an economic analysis

D.G. McFETRIDGE

This book examines the role of government in the allocation of resources to scientific research and development in industry. Starting from the premise that state intervention can be justified only if it increases economic efficiency, the study assesses the merits of alternative forms of government intervention, such as extending the scope of property rights to scientific discoveries, providing R&D subsidies, and government operation of research facilities. Focusing on the conditions under which subsidies should be granted, the enquiry considers the effects of such measures as the discrimination between foreign and domestic or between exporting and non-exporting applicants and the restriction to Canada of the exploitation of project results, and it examines the problem of determining the size of subsidy to be awarded.

An analysis of the current Canadian R&D subsidy assesses the extent to which subsidies may have been used to achieve alternative goals (such as support of failing firms), their effect on the total value of resources allocated to R&D, and the connection between research expenditures and patenting activity. Evidence is found that the present subsidy system has had the effect of increasing total R&D expenditures, which in turn has stimulated patenting activity. Whether the inventions obtained were worth their cost is left an open question.

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